February 1959

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NUCLEONICS

ATOMIC POWER • NUCLEAR ENGINEERING • APPLIED RADIATION

Nuclear Power for the Arctic

.....Army Reactor Program page 46

Hamner

COUNT RATE METERS and DECADE SCALERS

N-701C
LOGARITHMIC COUNT RATE METER

GENERAL DESCRIPTION

Designed specifically for direct counting of pulses resulting from nuclear disintegrations. There is a maximum-count limit switch that may be used to activate an alarm system or other external device, that will signal the presence of excessive radiation.

SPECIFICATIONS

HIGH-LEVEL INPUT: −50 to +100 volts
LOW-LEVEL INPUT: −0.25 to −5 volts
RANGES: 1) 1 - 1000 cps
2) 10 - 10,000 cps
3) 100 - 100,000 cps
4) 1 - 100,000 cps
OUTPUT: 0— 10 mv for recorder
LINEARITY: Better than 1%
STABILITY: 1% per day (after warm-up)

N-730
LINEAR COUNT RATE METER

SPECIFICATIONS

NEW!

RANGE: 9 full-scale ranges −0 to 10, 20, 50, 100, 200, 500, 1000, 2000, 5000 cps, covered by 4½" front panel meter. 1 microsecond scaler extends the range by another decade (50KC)
ACCURACY: ±¾ division on 10 mv recorder with a scale of 100 divisions. ±2% of front panel meter reading
STABILITY: ½% per day
TIME CONSTANT: 11 time constants available between ½ to 80 seconds
INPUT SENSITIVITY: Low level −.25 to −5 volts
High level −50 to +100 volts

N-230TP

N-220 DECADE SCALER

SPECIFICATIONS

SCALE: 10, 100, 1000
RESOLVING TIME: 1 microsecond
DISCRIMINATOR RANGE: −50 to +100 volts
ALTERNATE CHOICE OF LOW-LEVEL DISCRIMINATOR: −0.25 to −5 volts, for GM use
PRESET TIME: Mechanical timer with one hour capacity and an accuracy of ±0.1 second
PRESET COUNT: 10, 100, 1000
TEST: 60 cycle

N-230 DECADE SCALER

SPECIFICATIONS

SCALE: 10, 100, 1000
RESOLVING TIME: 5 microseconds
DISCRIMINATOR RANGE: −50 to +100 volts
ALTERNATE CHOICE OF LOW-LEVEL DISCRIMINATOR: −0.25 to −5 volts, for GM use
PRESET TIME: Mechanical timer with one hour capacity and an accuracy of ±0.1 second
TEST: 60 cycle

OPTIONAL EQUIPMENT FOR 220 & 230:

- L-F Timer for preset time or elapse timer
- positive high-voltage power supply 300 to 2500 volts 0-1 ma, .01% regulation line
- a plug-in, non-overload amplifier with RE clipping, gain 0 to 250

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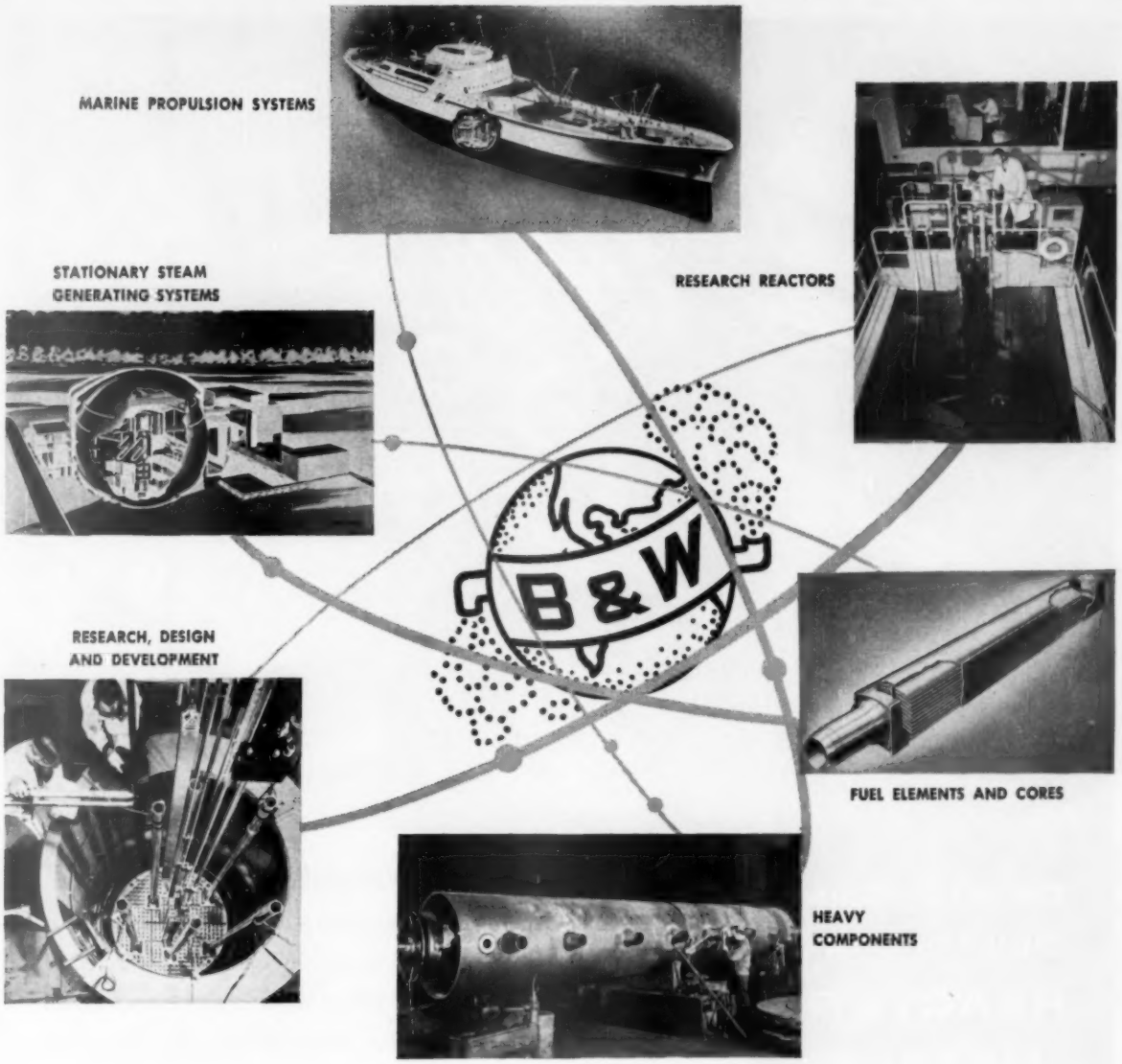

Some Of The Major Areas In Which B&W Is Contributing To Nuclear Reactor Development

From fuel elements to complete nuclear steam generators, Babcock & Wilcox is actively engaged in all phases of nuclear reactor development.

A skilled staff of scientists and engineers, specialized production facilities, programs of research for nuclear applications, together with long experience in controlling heat and pressure for productive purposes, have combined to establish B&W's position of leadership in putting the atom to useful work.

B&W recognizes that the development of nuclear power challenges industry with unprecedented, complex problems and is contributing to their solution—and to the Free World's progress and strength. The Babcock &Wilcox Company, Atomic Energy Division, 161 East 42nd Street, New York 17, New York.

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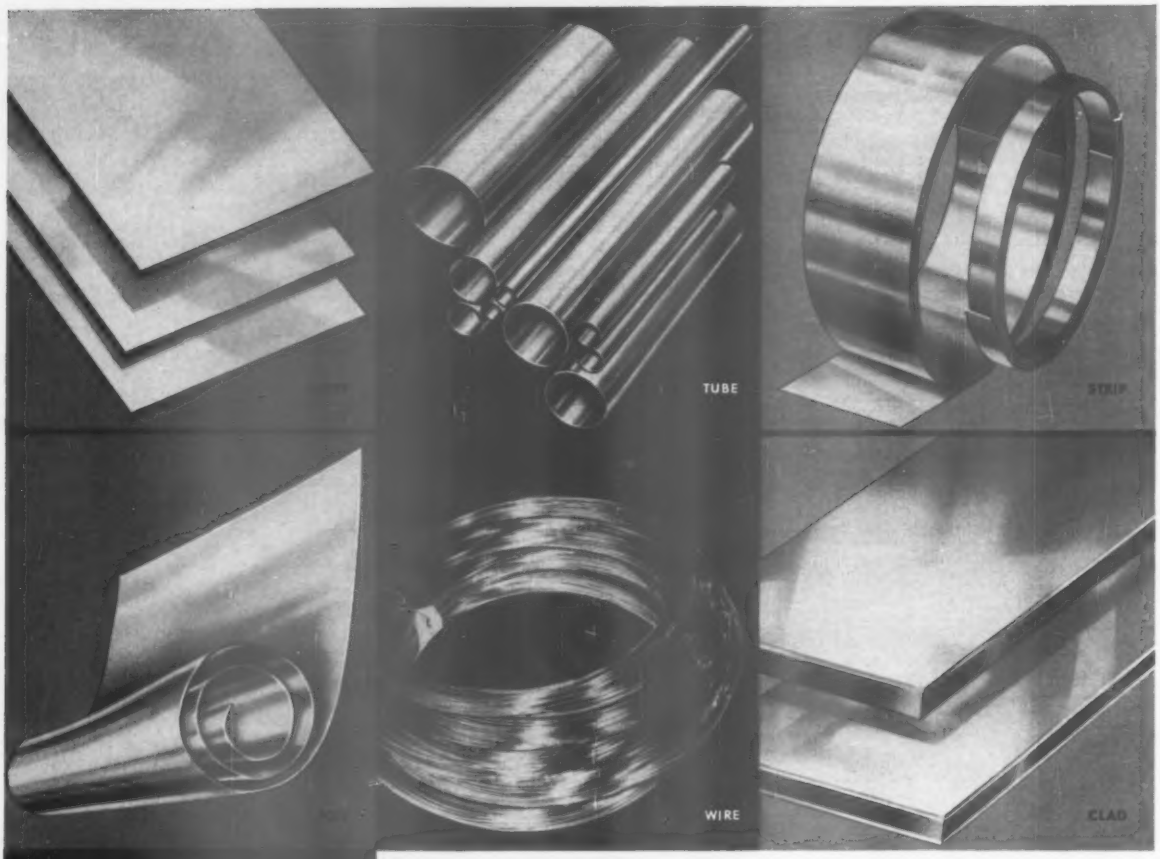

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NUCLEONICS

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APPLIED RADIATION

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More about NUCLEONICS on next page ▶

About NUCLEONICS

A Special Feeling

"There was a very special feeling evoked by my visit to the Argonne Low Power Reactor—ALPR makes sense, you can almost see it installed somewhere in the Arctic turning out power for a remote military installation. Maybe it is the way in which it's entirely mounted on concrete piers set on a slab to simulate permafrost construction, maybe it's the air-blast heat exchanger, maybe it's the olive-drab diesel-electric set provided for startup purposes—but something brings forcefully to mind an image of nuclear power at work.

"If I sound sold on this plant some of the credit must be due to the quiet salesmanship of the Argonne crew that designed and now operate it. They act like they really know what they're doing and feel really good about the reactor they have brought to life out here."

That extract from a letter sent back to New York by Managing Editor Dan Cooper during his visit to the National Reactor Testing Station last fall is a good introduction to what is but one facet of a surprisingly comprehensive Army nuclear power program. The aims and accomplishments of that program are described in the 15-page special report starting on page 46. Nuclear power makes good logistic sense today; it doesn't take much vision to see these same power packages fit into our civilian economy in the years ahead.

Incidentally, the structure towards which our friends on the cover are walking is a radome of the type used on the Distant Early Warning radar line. For the cover picture we are indebted to the Western Electric Co. which designed and built the DEW line for the U. S. Air Force.

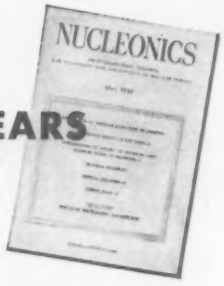
Siddall On Safety

At last year's Gatlinburg Conference on Reactor Control and Process Instrumentation one of the most controversial figures was a young Canadian named Ernest Siddall. His ideas on the use of redundant control elements and built-in testing thereof were, by turns, praised, damned or half-understood. So reported our editor in attendance at that meeting. That same editor, remembering with pleasure that these same ideas had been the subject of a well-received article in NUCLEONICS the year before (NU, June '57, p. 124) and further inspired by the conviviality of an ORNL-sponsored cocktail party joined in conversation with Siddall.

It turned out to be a good move, because Siddall was holding out eloquently on the subject of how much more safety the nuclear industry was demanding of itself than other industries had historically. He pointed out the lack of rationality of safety criteria —a lack that isn't surprising since human lives are involved. In those moments there was born the article that appears on page 64 of this issue—an article that might well be titled "How Safe Should Reactors Be?" We have iced the cake by including comments by reactor safety experts from several countries.

—*The Editors*

10 YEARS AGO



Neutron distribution. In 1949, diffusion theory was still regarded as something esoteric—"left largely to experts who are especially qualified by experience on the Manhattan Project." But after assuring the reader that "it is possible to go directly to the problem of interest and find the solution . . . as one does with a table of integrals" the author of this February, 1949 NUCLEONICS article provides him tabulation of solutions to the diffusion equation in several geometries with several source distributions. Still a convenient reference—even for those for whom the subject has become second nature. *Philip R. Wallace,* NUCLEONICS, *Feb. '49, p. 30; March '49, p. 48.*

Nucleonic events. News coverage occupied a modest 6 pages in the pocket-sized NUCLEONICS of February, 1949. The headlines in the Nucleonic Events department, as that news section was styled, tell their own story: "Hafstad Appointed Head of AEC Reactor Division" (he was the first, the Division had only been created a few months before), "Westinghouse to Build Reactor for Naval Ships" (this was the beginning of the Bettis Field laboratory, which was given responsibility for detailed engineering, construction and operation of the reactor.

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Next Month

D_2O Reactor Debate

Detection of Nucleate Boiling

Project Sunrise

Later Months

SENN Reactor

Special Report on Nuclear Instrumentation

Containment—A Review

New Team . . .

TITANIUM AND ZIRCONIUM

for your corrosion problem areas

TYPICAL CORROSION RESISTANCES OF ZIRCONIUM AND TITANIUM

CORROSIVE MEDIA	METAL RESISTANCE	
	ZIRCONIUM	TITANIUM
Sulfuric Acid	excellent to good below 80%	good below 5%
Nitric Acid	excellent	excellent
Hydrochloric Acid	excellent	good below 10%
Phosphoric Acid	excellent to fair below 85%	poor
Chromic Acid	excellent	excellent to good
Aqua Regia	poor	excellent
Wet Chlorine Gas	poor	excellent
Chlorine Water	excellent	excellent
Sodium Hydroxide	good below 90%	good below 50%
Ferric Chloride	poor	excellent
Calcium Chloride	excellent	excellent
Cupric Chloride	poor	excellent
Sodium Chloride	excellent	excellent
Ammonium Chloride	excellent	excellent
Aluminum Chloride	excellent	excellent to fair

Chart shows corrosion resistances of zirconium and titanium to typical chemicals.

Steam jet made of zirconium, which has given trouble-free performance after a year in hydrochloric acid service. For comparison, a throat piece from a steam jet (below) is shown after only a week of similar service.

By specifying titanium or zirconium for processing equipment, you can now overcome most of the corrosive media which attack other metals.

Even with such hard-to-handle chemicals as chlorides and oxidizing acids, equipment can have extremely long service life when made from these corrosion-resistant materials. Problems of product contamination in chemical and food processing can also be virtually eliminated.

Mallory-Sharon is in position to offer you *both* titanium and zirconium mill products for equipment fabrication—plus engineering assistance and unbiased recommendations on the most suitable material.

Titanium is now available from stock in a complete range of mill products, may be readily fabricated, and more than pays its extra cost where ordinary metals fail. Zirconium facilities are being rapidly increased, and mill shapes are now in production.

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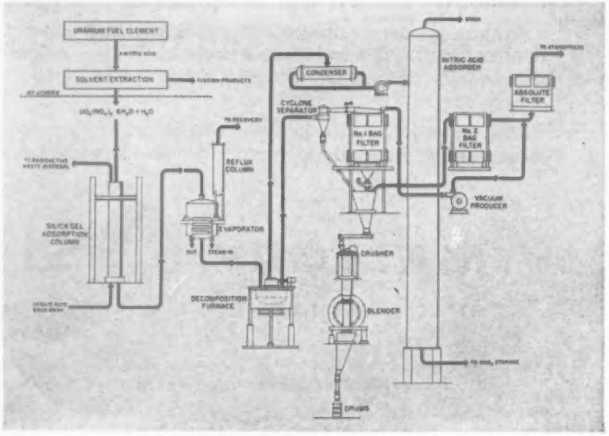
Heavy Water Area, Savannah River Plant. Lummus handled design, engineering, procurement and construction liaison of this area.

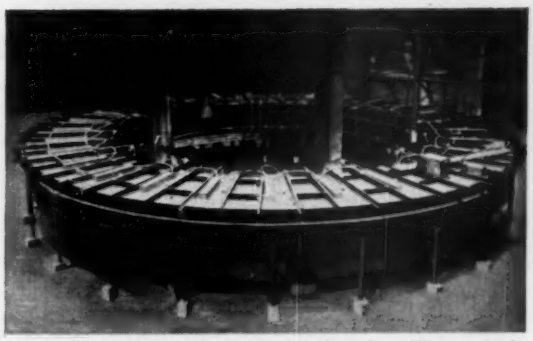
Nitric Acid Recovery Unit of the Savannah River Plant Chemical Separations Plant. Lummus handled design, engineering, procurement and construction liaison of this unit.

World-wide designers, engineers and constructors of over 800 major plants for the process industries in the last half century, Lummus now offers its experience for the development of atomic energy installations. Here are some current examples of Lummus work in this field:

Uranium Oxide Recovery Unit of the Savannah River Plant. Lummus handled design, engineering, procurement and construction liaison of this unit.

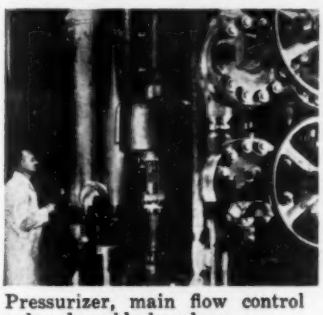


Plant engineered and designed by Lummus for Beryllium Corporation to extract beryllium metal from beryl ore.

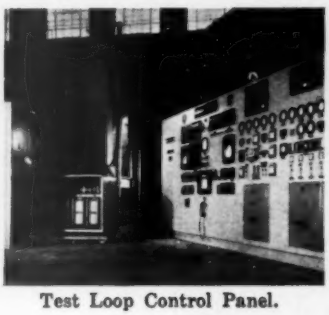


Ore sintering furnace used to produce beryllium metal.

Below is the high pressure, high temperature test facility, constructed by Lummus at its Engineering Development Center for the Knolls Atomic Power Laboratory. The facility consists essentially of a pressurized water heat exchange system and demineralizing equipment. Reactor fuel and materials samples are inserted in the in-pile test section for study under controlled conditions of temperatures, pressure, radiation flux, and water conditions.



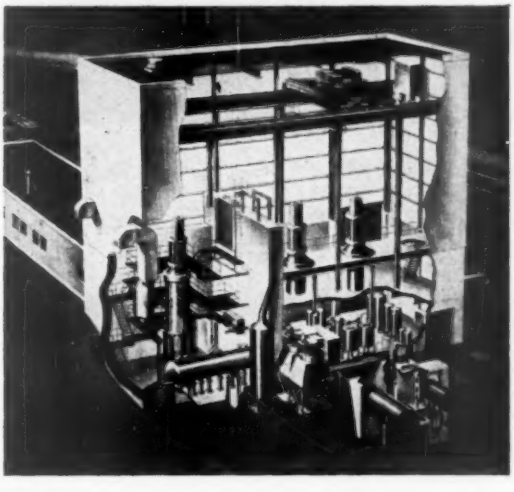
Pressurizer, main flow control valve, loop block valves.

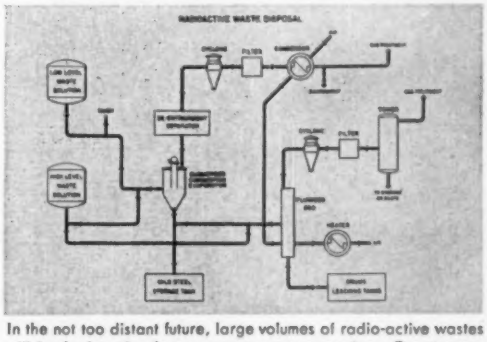


Test Loop Control Panel.

Four loop pump volutes with special cover plates for hydrostatic testing.

This high temperature test facility was designed and engineered by The Lummus Company under sub-contract to Westinghouse Electric Corporation, Bettis Atomic Power Division. Its purpose is to make criticality measurements and to determine flux distributions in water moderated reactors operating at low power levels and elevated temperatures and pressures.





In the not too distant future, large volumes of radio-active wastes will be forthcoming from power reactor operations. Great quantities of this material are now being stored in costly underground tankage. We believe that it would further reactor development to have a more economical and safe waste disposal system to take care of the large radio-active waste volumes. The Lummus approach to this has been directed toward utilizing known engineering techniques which require special consideration due to the unique problems associated with radio-active waste.

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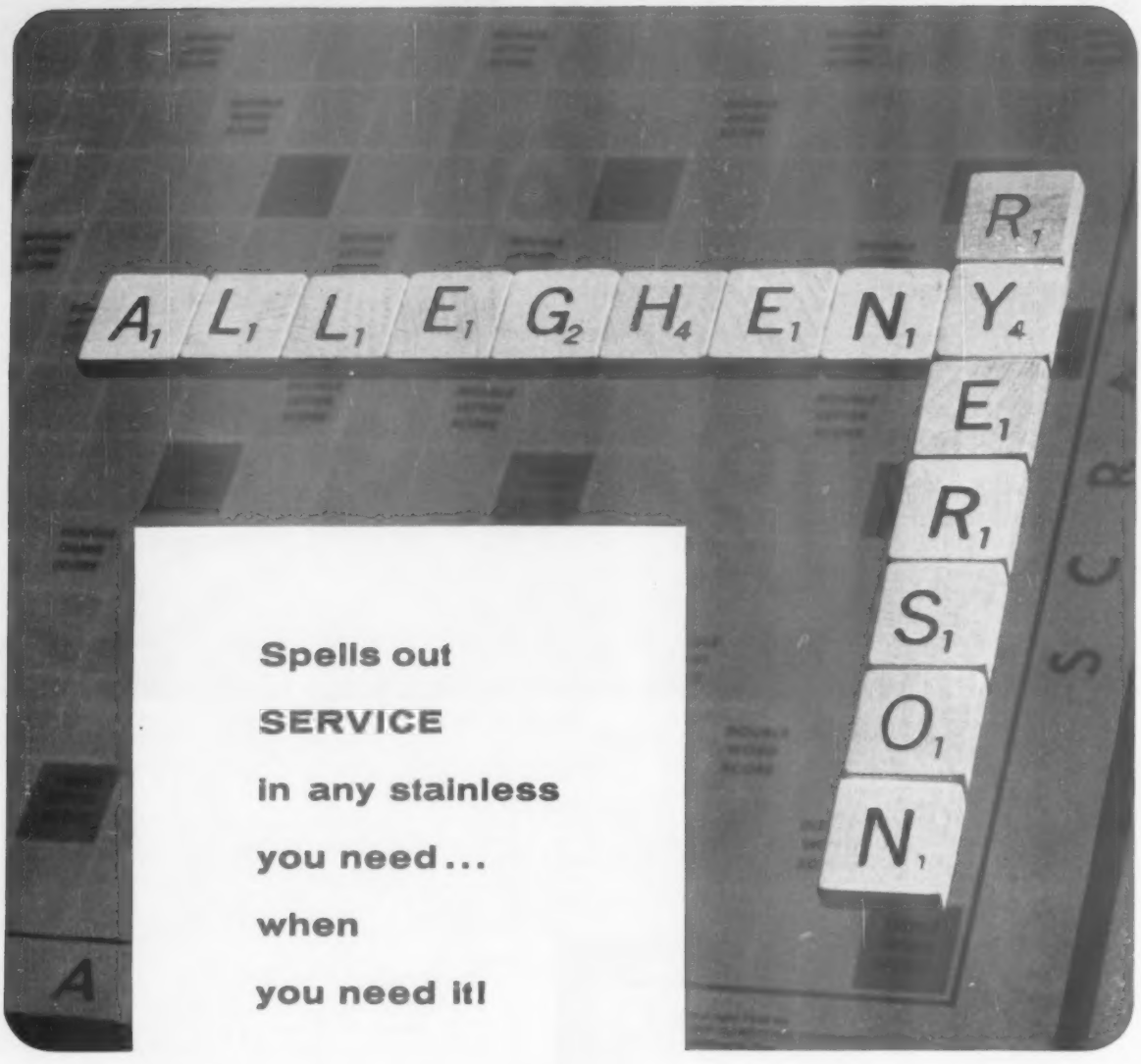

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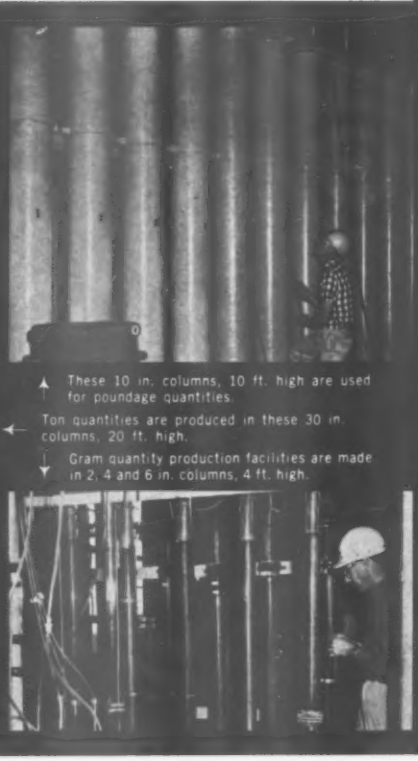

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← Ton quantities are produced in these 30 in. columns, 20 ft. high.

↓ Gram quantity production facilities are made in 2, 4 and 6 in. columns, 4 ft. high.

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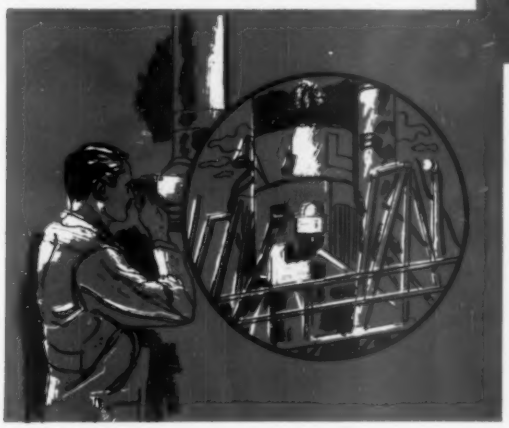

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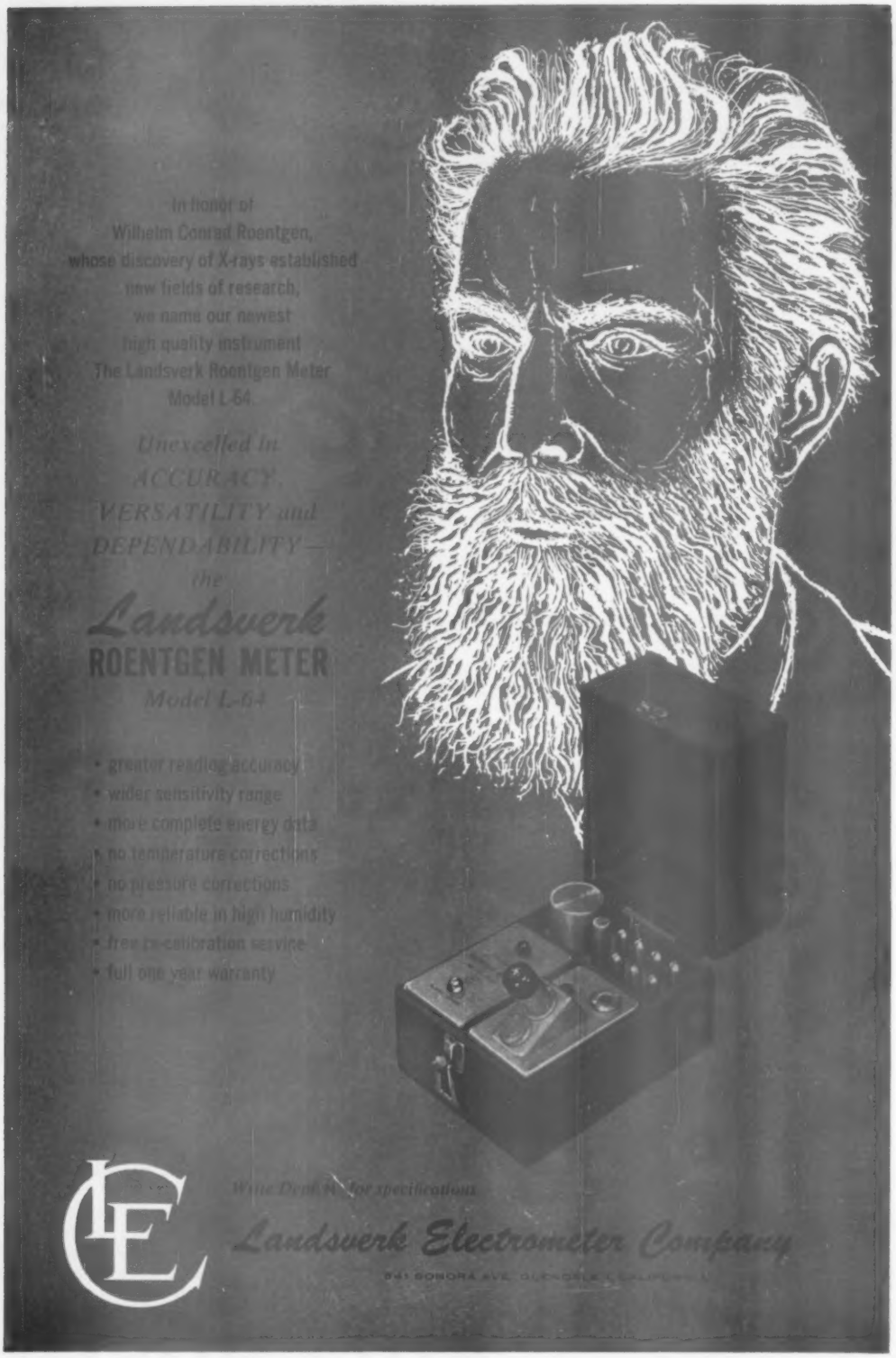
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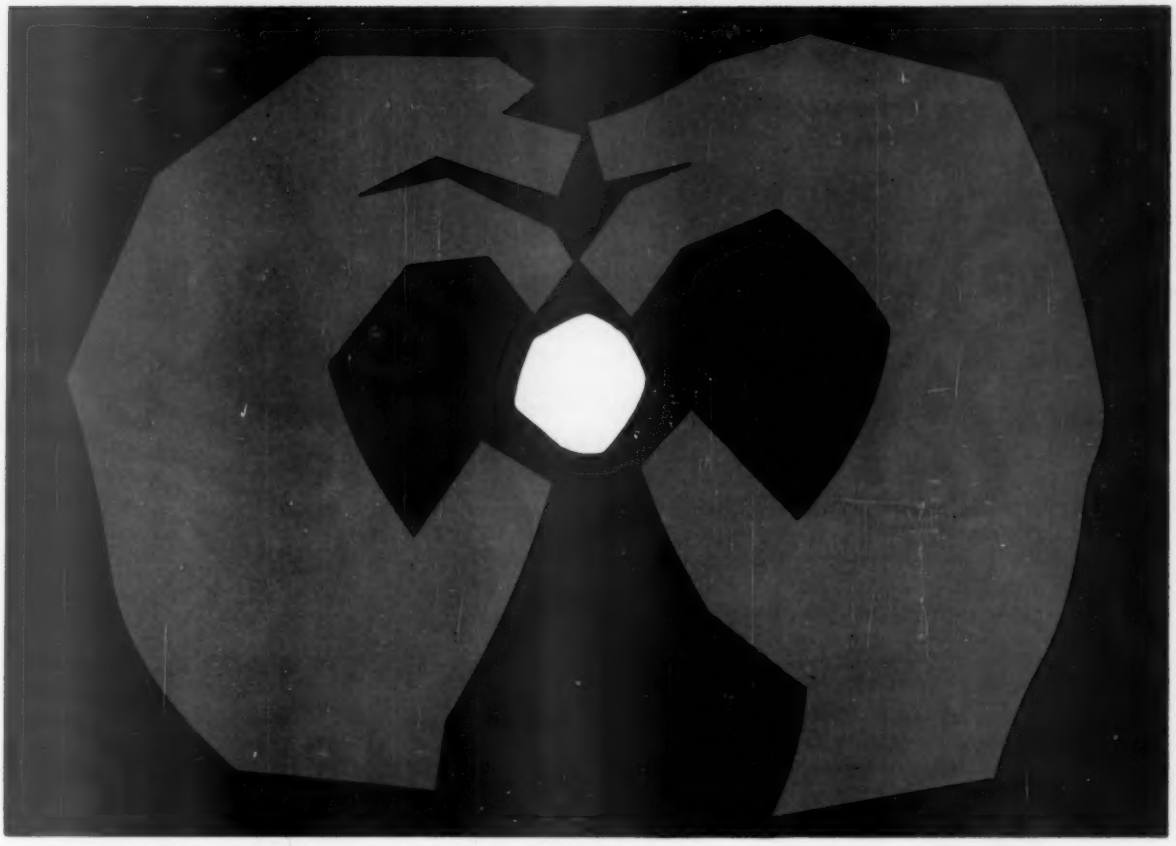

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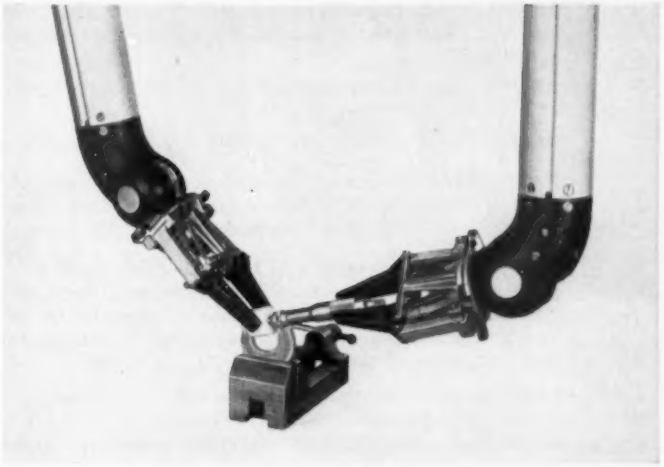

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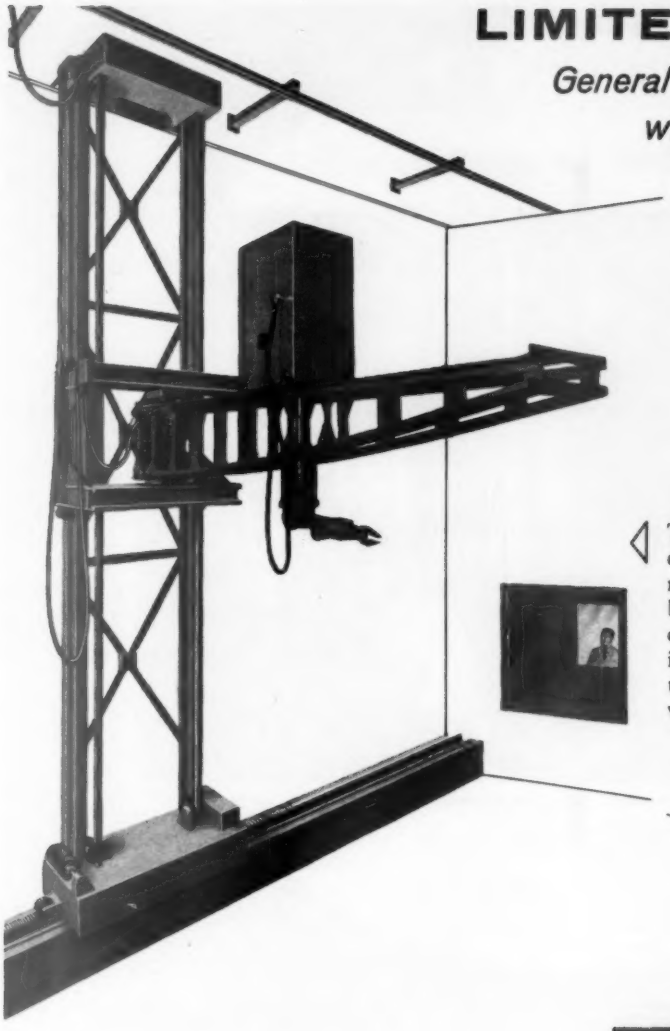

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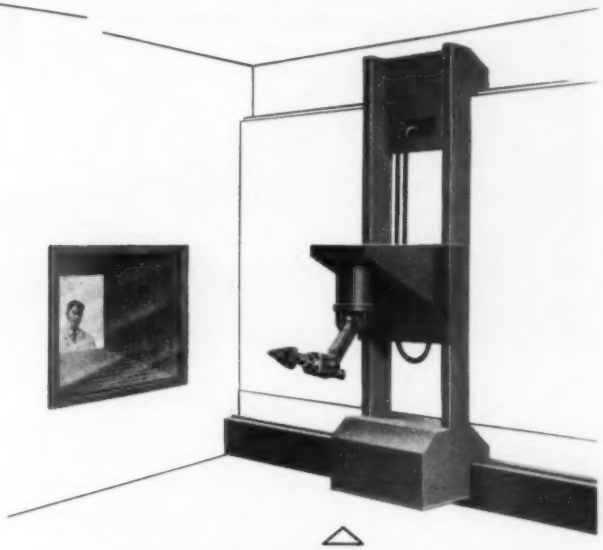

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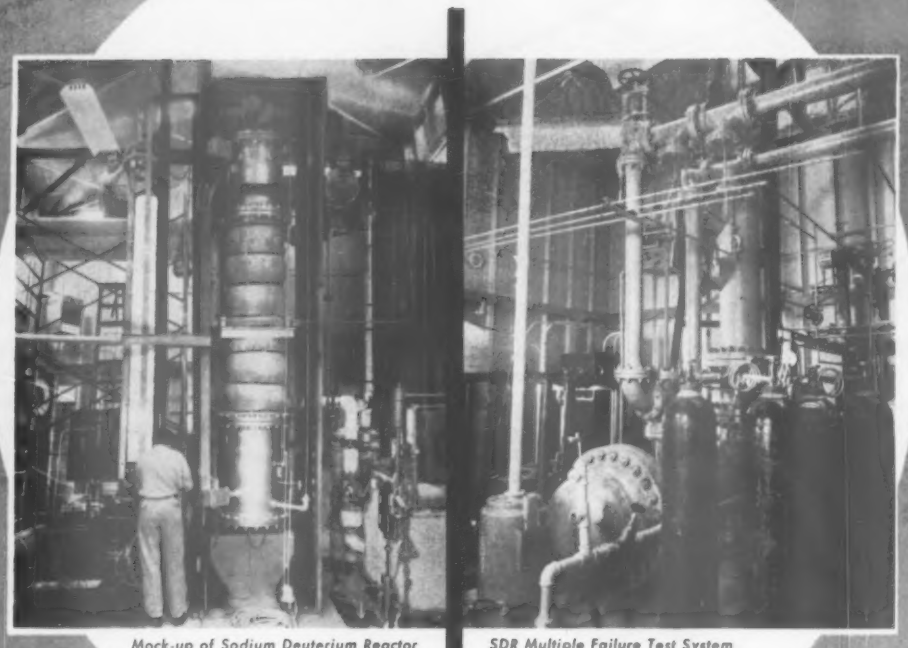

Mock-up of Sodium Deuterium Reactor

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ROUNDUP of Key Developments in Atomic Energy

Acceleration Gains in Face of Budget Bureau Dollar Limit

Acceleration, for the past three years the focus of the debate over government nuclear power policy, was buffeted by both favorable and unfavorable winds in January, but managed to make a net gain as the 86th Congress convened for what all expect to be the crucial year for atomic power policy.

As the Joint Committee on Atomic Energy approached its annual "202" hearings in late February, acceleration stood closer than ever to agreement by all concerned. But implementation was jeopardized by the public-vs.-private-power controversy (*see page 21*) and the determined effort of the Eisenhower Administration to hold the 1960 budget at $77-billion.

Nevertheless, on balance, the outlook for acceleration was at its brightest—chiefly for these reasons:

- The AEC ad hoc committee on reactor policies and programs (NU, Nov. '58, 25; Dec. 20), appointed by AEC Chairman McCone, recommended an acceleration of U. S. effort to achieve competitive nuclear power; its report was submitted to AEC on Jan. 2.
- Congressional sources expressed confidence that an AEC-JCAE agreement this year on acceleration would override most Budget Bureau opposition.
- Hope was also expressed by Congressional sources that the public-private power issue could be met by adoption of a compromise program that would make more money available for both AEC and non-AEC sponsored new reactors. A compromise along these lines was already in prospect for the gas-cooled reactor (*see page 21*).

Further budget details on p. 20.

. . . as AEC Advisory Group Urges 'Vigorous' Acceleration

AEC's special advisory committee on reactor policy joined the Democratic majority in Congress' Joint Committee on Atomic Energy in calling on the Administration for an accelerated civilian reactor program. It urged "a vigorous development program" to make nuclear power economic in the U. S. in ten years.

The Tammaro-Smyth committee —officially the AEC Ad Hoc Advisory Committee on Reactor Policies and Programs (NU, Nov. '58, 25)—outlined, in a 60-page report submitted on Jan. 2, U. S. nuclear power needs, an appraisal of the present status of development, and suggestions for the future. The report itself gave in summary form five objectives (*see box*), 16 technical and seven general recommendations (*below*).

Broadly speaking, the New Smyth Report (as it is already being called) recommends roughly the same reactor concepts for development and the same technical goals as did JCAE in its staff study on acceleration last summer (NU, July '58, 17). It casts doubt—at least by implication—on whether the time is ripe for construction of second- and third-generation reactors, either by industry or government, indicating rather a strong preference for concentration on small pilot plants.

It agrees with the JCAE Democratic majority that more positive leadership by AEC is required. It flatly contradicts what had been a major premise of AEC policy during the chairmanship of Lewis L. Strauss, that private industry should bear the main responsibility for development and building of nuclear power plants: the report declares that while nuclear technology is "well advanced" in the U. S., "it still has a long way to go before it can be turned over entirely to private industry."

It also criticizes AEC for not yet having determined with any degree of accuracy the η-value* of U^{233}, recent indications having cast doubt on whether it is high enough to permit efficient thermal breeding using the thorium–U^{233} cycle.

* η (eta) is defined as the number of neutrons emitted per neutron absorbed, whether by fission or radiative capture.

Recommendations, Technical

An introductory section entitled "Recommendations for the Technical Program in the Near Future" reads [following matter is practically verbatim]:

Our conclusions are that the technology of nuclear power is well advanced in this country, that it still has a long way to go before it can be turned over entirely to private industry, and that if the AEC leads a vigorous development program there is a fair chance that nuclear power may be competitive with power from fossil fuels in some parts of this country within 10 years and in most of the country within 20 or 30 years.

We have reviewed the present status of the technical program and find it generally sound. To strengthen it and give it guidance particularly in the immediate

Objectives for the U. S.

AEC's Ad Hoc Committee, named last fall by Chairman McCone, said it believes the five principal objectives of the civilian nuclear power program in the U. S. are to:

"A. Fortify the position of leadership of the U. S. in the technology of nuclear power for civilian use;

"B. Reduce the cost of nuclear power in this country to a point competitive with power from fossile fuel at least in some areas within 10 years;

"C. Reduce the cost of nuclear power to the competitive point in friendly foreign nations having high costs for energy in less than 10 years through a comprehensive program of assistance clearly defined and vigorously pursued;

"D. Achieve a substantial reduction in the cost of nuclear power over the next 20 or 30 years by continuing studies which may ultimately lead to great cost reductions, but which are unlikely to bear fruit in the next 10 years;

"E. Make the fullest use possible of the nuclear energy latent in both uranium and thorium, especially by breeding, recognizing that U^{235} alone is probably not sufficiently plentiful to contribute significantly to our power needs over the long range."

future we have made a number of recommendations . . . :

1. A broad program of general applied research should be generously supported by a substantial increase over the level of fiscal '59 expenditures for this category of work. In addition, some of the work now being done under specific reactor projects should be transferred to this program.

2. Within the program of general applied research, increased effort should be put on the fuel cycle, including fuel element fabrication.

3. Within the program of general applied research, increased effort should be put on reactor physics, including the determination of eta for U^{233} and other similar constants.

4. Construction of further prototypes [pilot plants designed with ultimate construction of a large plant in mind] of boiling water reactors that advance the art should be encouraged. Studies being carried out by AEC and by industry will probably indicate the desirability of constructing one or two of these starting in 1959. If further studies on pressurized water reactors bring forth promising new ideas, prototype reactors of this kind should also be constructed.

5. Work on nuclear superheat should be directed toward incorporation of this feature in a prototype reactor at an early date.

6. Work on pressure tubes and pressure tube reactors including that recently initiated is commended and should be continued, since this offers a possibility of unlimited reactor size and a promising method of achieving nuclear superheat.

7. Since the concept of organic cooling looks attractive from the point of view of reducing capital costs, a further reactor experiment or prototype reactor should be started in 1959 if present design studies, particularly those on heavy water moderated and organic cooled reactors, come to promising conclusions.

8. The general work on sodium as a coolant should be encouraged by continued operations of the Sodium Reactor Experiment and by pushing the new development work on sodium systems. Construction of the Hallam plant is probably advisable but should be given a lower priority than the general work.

9. The thorough investigation of a sodium-cooled and heavy-water-moderated reactor should continue.

10. Since there is a need for a flexible reactor test facility and for experience with a gas-cooled, civilian power reactor at an early date, a reactor similar to that designed by Kaiser Engineers and ACF Industries should be constructed starting in 1959. Flexibility should be introduced into the design to make the reactor suitable for testing fuel elements for gas-cooled reactors at temperatures up to 1,400° F.

11. Research and development support should be continued for the gas-cooled, heavy-water pressure-tube reactor proposed by the Florida West Coast-East Central groups.

12. Subject to the present technical review by AEC, the Commission should support the research and development required for the advanced gas-cooled reactor proposed by the Philadelphia Electric Co. Support should also be continued on the somewhat similar concept of the pebble-bed reactor.

13. The aqueous homogeneous, molten-bismuth, and molten-salt reactors all offer the possibility of reducing the cost of the fuel cycle, and the last two offer the possibility of high-temperature operation. These three concepts for power reactors should be critically compared and work concentrated on the concept that appears most promising.

14. Work on reactors involving the U^{233} breeding cycle should be reduced until it is clear that the value of eta is such as to make breeding feasible. Such breeding may require use of slurries, and work should continue on developing slurry-handling technique.

15. Work on plutonium as a fuel should be pushed and the necessary facilities for this work provided.

16. Work on fast breeders should continue to get vigorous support.

Broader General Recommendations

1. To promote better understanding of the U. S. nuclear power program, both in this country and abroad, AEC and JCAE should issue a formal statement of objectives.

2. This statement should explain the necessity for leadership by the Federal Government, in cooperation with industry, and describe how this leadership is to be exercised.

3. Possible methods of government assistance in implementing the program should be examined with a view to maximum flexibility and minimum distortion of technology.

4. The U. S. should continue cooperation with and support of the International Atomic Energy Agency, Euratom, and other international programs.

5. The technical program should give special emphasis to such factors as neutron economy in order to promote the most efficient use of fissionable and fertile materials.

6. Pilot plant reactors should be emphasized rather than large power reactors until the latter can be wholly or nearly self-supporting.

7. Ad hoc committees such as the one here reporting should be appointed from time to time to review the program.

Budget Bureau Orders AEC to Hold Spending Line; Cuts Unlikely with JCAE in No Mood to Accept Them

That the Budget Bureau, more than ever, will be a force to contend with, was clear from its unshakable stand on imposing an arbitrary ceiling on AEC's budget for fiscal '60. The Bureau simply ordered AEC to hold to fiscal-'59 levels of spending. Its stand not only stifled any idea AEC may have had for accelerating reactor development on its own, but made it clear that any joint AEC-JCAE acceleration program will have tough sledding.

The commission's own civilian budget recommendations have been deeply slashed by the Budget Bureau (NU, Jan. '58, 23). As one AEC source explains it, "This wasn't a case of the Budget people exercising technical judgment on individual parts of the program. They just set a dollar ceiling, and invited us to split it however we wish. The effect is to limit the number of reactor concepts which can be pursued in fiscal '60."

An AEC official, when asked what will happen if budget limitations continue to be imposed on the reactor development program beyond next fiscal year, replied that "we would be forced to make a drastic revision in the program."

From a realistic view, this is extremely unlikely to happen.

Whatever the attitude of the President's Budget Bureau, JCAE is bound to authorize an expanded program—and there's widespread belief that it will have the behind-the-scenes cooperation of AEC in so doing. In fact, there's speculation the Commission hopes to submit a supplemental budget request later this year.

However, two factors will act as a brake on actions by JCAE and the appropriations committees: the

Democrats cannot allow themselves to appear as "reckless spenders" for projects not essential to national defense; and, if President Eisenhower stands firm, there is no way Congress can make the administration build reactors it doesn't want, even if authorization and funds are voted.

Washington observers are convinced that Chairman McCone, if determined himself that the reactor development program should be accelerated, can do much to reconcile the differences between the Democrats and the Budget Bureau.

Since other nations favor natural uranium as a fuel, heavy water reactors qualify as a favored concept for the foreign program. Plutonium recycling reactors are another, in light of desire abroad to burn Pu.

For domestic development, according to staffers in the Reactor Development Division, any list of priority concepts includes boiling water, pressurized water and organic moderated. Gas-cooled reactors, for political as well as technical reasons, qualify for the list. The desire for neutron conservation makes the fast breeder a strong candidate.

Concepts that appear most likely to suffer from budget limitations:

- The sodium-cooled reactor. AEC expects to continue improvement of the Hallam, Neb., design during its construction, but plans for construction of a second sodium reactor experiment may be delayed.
- The fluid-fueled reactors. AEC experts are anxious to press development of one of three fluid-fueled concepts—homogeneous, fused salt or liquid-metal-fueled reactor. The stock of the homogeneous concept has fallen as a result of the suspension of the P.P.&L.–Westinghouse project (*see p. 61*).

Reactor Subsidies Gain Private Utility Acceptance; Public Power Demands More AEC-Built Reactors

The Democratic-dominated Joint Committee on Atomic Energy returned to work last month and found awaiting it a solid endorsement from the nuclear power industry for a long-range, accelerated reactor development program. But with the endorsement came an eruption of the public-vs-private power issue in its most outspoken terms. These were the highlights of a 218-page compendium released by the Joint Committee shortly before the 85th Congress convened on Jan. 7. In its pages were some 70 commentaries by reactor experts, equipment manufacturers, private and public utility interests and architect-engineering firms on the "proposed expanded civilian nuclear power program" sponsored by the JCAE staff (NU, Sept. '58, 155, Aug. '58, 18).

The document revealed a virtually unanimous agreement by all four of these segments of the nuclear power industry that the federal government should step up its spending on reactor development. As never before, however, the compilation demonstrated the width of the breach among public and private power executives over how the federal monies should be committed.

The JCAE document amounts to a preview of industry testimony at the annual "202" hearings scheduled to start later this month. To the same extent, the compendium gives an insight to what the Committee was told by industry people who attended a three-day symposium at the Capitol in mid-January.

Generally, private power demands a continuation of the partnership policy under which reactors beyond the experimental stage are sponsored by the utility industry; seeks repeal of the preference clause of the 1954 Atomic Energy Act (giving public power bodies first call on federally-produced electricity); and supports the principle of federal subsidy to get more reactors built under utility sponsorship.

Public power favors a reinstatement of the second-round philosophy of the reactor demonstration program (AEC ownership of reactors hooked on to publicly-owned generators); demands retention of the preference clause; and brushes aside the subsidy concept in favor of outright construction of development reactors by the Commission itself.

A significantly larger fraction of the private utility industry has swung behind Willis Gale of Commonwealth Edison in support of the incremental subsidy approach or some modification of it under which AEC would put up the difference in construction and/or operating costs of a nuclear power plant over a conventional station. The Gale plan has also been embraced by JCAE Chairman Clinton P. Anderson (NU, July '58, 18). Philip Sporn of American Electric Power Co., J. Robert Welsh of Southwestern Electric Power Co., and H. W. Balgooyen of American & Foreign Power Co., all spoke out for capital subsidies in their latest comments.

Opposition to HTGR foreshadows delay

Stiffening opposition within AEC and the Joint Committee on Atomic Energy indicated last month that the private-utility-sponsored high-temperature gas-cooled reactor (HTGR: NU, Dec. '58, 17) may be delayed in favor of the less-advanced design of ACF-Kaiser Engineers (NU, Aug. '58, 118). As the Feb. 21 deadline neared for an AEC decision on accepting the HTGR proposal, AEC staff people were reflecting a growing sentiment that the concept was too advanced for early construction; one official commented: "It would take not only development, but invention." Congressional sources were talking up a compromise under which construction would proceed on the less daring concept and a construction commitment on HTGR delayed pending further study.

Los Alamos criticality accident kills technician

Third person to die of radiation injury in the U. S. atomic energy program (and first since 1946), Cecil W. Kelley, 38, a metal fabrications operator at Los Alamos, died Jan. 1—36 hours after a criticality accident in a plutonium-waste stirring tank. Investigation is underway. Kelley, 11 years a LASL employee, told of seeing a blue flash as he started a stirring motor in a 225-gal, 5-ft-high, 4-ft-dia closed (but unshielded) tank, part of a process for Pu recovery from waste solutions. He had performed the task some 75 times before; the tank had operated safely some 1,000 times. Attending physicians estimated he received 10,000 rem.

New Labor Group Plans Louder Voice on Atom

The AFL-CIO, powerful voice of organized labor, has discarded its relatively aloof posture on the peaceful atom for a more active role vis-a-vis the policymaking and regulatory activities of the federal government and the health-and-safety activities of the nucleonics industry.

The breadth of the new role was spelled out to NUCLEONICS last month by Benjamin Sigal, chairman of the new 14-member, technical advisory committee to the AFL-CIO Industrial Union Dept. (NU, Dec. '58, 27) and chief counsel for the three labor unions demanding withdrawal of the construction permit given the Fermi Project at Lagoona Beach, Mich. (NU, Jan. '58, 23). Reporting on the committee's organizational meeting in late November, Sigal said the group will:

1. Press for an "adequate program for the development of peaceful uses of atomic energy" in the production of electric power and the use of radioisotopes. It will concern itself particularly with the civilian reactor development program, implementing the AFL-CIO policy in favor of stepped-up reactor construction by AEC.

"The committee, in all likelihood," he said, "will support a much more vigorous program of power reactor development than we have seen up to now."

2. Work for fullest protection of health and safety of workers in facilities processing or utilizing radioactive materials, and take a more active part in the hazards education of union leadership and members so they will be better able to demand adequate safeguards from management.

The committee will also have something to say on where the line should be drawn between state and federal authority, Sigal said. "For the present," he declared, "this is a matter that should be left primarily in the hands of the federal government. Generally speaking, the states do not have the trained personnel at this stage."

3. Support establishment of a federal workmen's compensation program for atomic energy labor. State compensation measures, according to Sigal, are inadequate to cover radiation hazards, in particular are deficient in the time allowance for making injury claims, since radiation injury may be much longer in manifesting itself than the year generally allowed by the states.

4. Emphasize on Capitol Hill an alleged conflict in AEC's responsibilities for both regulation and promotion of the peaceful atom. "In view of the [Fermi] case," he contended, "there is a serious question whether it is proper to have responsibility for the promotion and the regulation of atomic energy applications under the same roof."

Sigal's committee was organized by Walter Reuther, chief of both the United Auto Workers and the Industrial Union Dept., who has been a loud critic of AEC's way of doing business and a long-time advocate of reactor acceleration. As a member of the McKinney Panel (NU, Feb. '56, 9), he wrote a separate report urging a crash program of civilian reactor development. As head of UAW, Reuther has been the prime mover in the labor fight with AEC over the Fermi project.

He has organized the advisory committee in his AFL-CIO department at this time, he explained, because the latest Geneva Conference "revealed widespread application of radioactive materials throughout industry and science. This brings the potential application of nuclear science into thousands of plants, factories, mills and mines. The introduction of this new technology and science raised many problems for the workers in such places." Sigal said his committee will not make policy; rather it will give advice to Reuther and other top officials of IUD. Once policy is set, however, the committee will function as the voice through which it is brought to the attention of Congress, the Administration, the public and the membership.

Membership

Secretary to the committee is Leo Goodman, atomic energy adviser, UAW. Committee members include Frank Burke, United Steelworkers; Joseph Childs, United Rubber Workers; Joseph A. Fisher, Utility Workers; Timothy Flynn, American Federation of Technical Engineers; Sandford Gottlieb, American Federation of State, County and Municipal Employees; John J. Grogan, Marine and Shipbuilding Workers; Tom Lloyd, Amalgamated Meat Cutters; James M. Massey, Communications Workers; Brooks Payne, International Brotherhood of Electrical Workers; Joseph F. Phillips, Plumbers and Pipefitters; Elwood Swisher, Oil, Chemical and Atomic Workers; Elmer Walker, International Assn. of Machinists; and (indicated) Charles F. McGowan, Boilermakers Union.

6 Mergers in A-Industry; Zinn Atom Chief at CE

The wave of mergers in the nuclear industry that was building up at year's end (NU, Jan. '59, 25) broke last month, carrying along even a pair of labor unions. All in all, twelve organizations said "Let's do it," reducing their aggregate number to six.

Top headliner among the mergers was the acquisition of Walter F. Zinn's General Nuclear Engineering Corp. by Combustion Engineering Inc., to form a significantly strengthened contender in the reactor world. Zinn is slated to become a vice-president of Combustion, with centralized responsibility for the firm's nuclear operations from offices in Windsor, Conn. His colleagues in GNEC will remain at Dunedin, Fla., for the foreseeable future, with the group operated there as a Combustion subsidiary.

Metals and Controls—as also forecast by NUCLEONICS last month—voted to merge with Texas Instruments. The other four mergers:

• Sylvania Electric Products, Inc. was merged into General Telephone Corp. which changed its name to General Telephone & Electronics Corp. General Telephone controls a number of operating telephone companies, directory-publishing firms and manufacturing and sales concerns. Sylvania will continue operations as a separate corporate entity, and Sylvania-Corning Nuclear Corp., a joint subsidiary of Sylvania and Corning Glass making fuel elements, expects no change in its operations as result of the move.

• Salem-Brosius Inc. of Pittsburgh acquired R. H. Freitag Manufacturing Corp. of Akron to form a major integrated supplier of reactor components. Freitag, with a 110,000-ft² plant for equipment and precision machined parts, will be operated as a divison of Salem-Brosius' wholly-owned subsidiary, Alloy Manufacturing Co., Pittsburgh. Salem-Brosius, built up since 1950 by mergers of small long-established firms, is a prominent designer and builder of furnaces for the steel and metallurgical industries; by acquiring Alloy last July, it entered the naval reactors program as a supplier of precision-welded core components.

Salem-Brosius has initiated a $500,000 expansion of the Alloy plant.

• Sabre-Pinon, prominent uranium mining and milling firm, will acquire Black Jack Corp., a land-holding concern controlling 15,436 mineral-bearing acres in New Mexico.

• The Oil, Chemical and Atomic Workers Union and the International Chemical Workers Union have drafted a proposed constitution for a merger of the two labor groups.

Combustion and GNEC

Combustion is giving GNEC 65,412 shares of Combustion stock, worth about $2-million, at a rate of 7 shares for each 10 shares of the 81,002 authorized and outstanding shares of GNEC (plus 2,131 shares of preferred stock and 2,000 shares involved in a restricted option).

Combustion has some 2,300 employees in its nuclear operations, divided roughly as follows: scientists and engineers, 300 at Windsor and 100 at Chattanooga; draftsmen, 50 and 90; production workers, 1,050 and 700. GNEC had 36 engineers and scientists and 23 design draftsmen, administrative and supporting personnel as of Nov. 1.

Combustion feels that addition of the experience- and prestige-rich design team of GNEC so broadens its own technical base that it will be able to compete much more aggressively than it has done in the international market for reactor jobs. "It gives us an ability in all kinds of reactors that we haven't had," one executive put it. Present nuclear backlog on civilian and military projects is put at $45–50 million.

Metals & Controls and Texas

Texas Instruments is acquiring Metals & Controls for $48.3-million, by an exchange of stock, with the holders of the 922,467 M & C common shares receiving ¾ of a share of Texas Instruments, quoted at 69 on the N. Y. Stock Exchange at year's end. Texas Instruments, a 29-year old firm, has 7,500 employes and did $90-million sales in 1958. It makes electronic and electromechanical systems for military and civilian uses, transistors and other semiconductor devices, and is prominent in geophysical exploration for oil with prospecting crews in 20 countries.

C. J. Thomsen, director and vice president of Texas Instruments, was elected president of Metals & Controls as of Jan. 5; George Williams, former acting president, remains as president of M & C Nuclear.

Hoops in Britain: New Reinforcing Technique Permits Doubling Power Output of Gas-Cooled Reactors

Spectacular increases in specific output thanks to a major structural breakthrough in reactor design are expected to distinguish at least two forthcoming bids for the 500-Mw(e) second-round nuclear power station at Trawsfynydd in Wales.

These designs for the first time use cylindrical reactor vessels with hoop reinforcement. The banded reinforcement ideally halves the hoop stress—the maximum design stress—in the reactor shell compared with that of a plain cylinder having the same plate thickness.

The great significance for the future of the British nuclear power program of this development is that it allows gas pressures to be approximately doubled, and consequently power output nearly doubled.

One of the designs is by AEI–John Thompson, which submitted a bid this month for the Trawsfynydd station. It is believed that in the 250-Mw(e) reactor design AEI is currently offering, the diameter is even smaller than the company's 138-Mw(e) reactor now building at Berkeley, while using plate of basically the same thickness.

Although the immediate objective of the development was the achievement of higher gas pressure without recourse to plate thicker than the current 3–3½-in., K. G. Mantle of the John Thompson design team told NUCLEONICS that the technique has vast potential.

Manufacture and on-site welding of plate much thicker than 3½ in. is currently one of the most urgent and serious problems in the development of Calder-type reactors. Already each plate requires one whole ingot, and very little hot-working is possible during its reduction. This leads to serious lamination in the plate and loss of ductility as the plate partly retains the cast structure of the ingot. Every square inch of plate requires the most exhaustive application of ultrasonic testing, and wastage is believed to be considerable.

On site, existing equipment for radiological weld-testing is not able to detect fine cracks in plates exceeding this order of thickness.

In general, reinforcement of a pressure vessel by hoops or bands leads to larger, thinner plates which offer two advantages: greater ductility and fewer welds in both large and small pressure vessels.

AEI declines comment on its reinforced technique, but NUCLEONICS understands that laminated bands built up from possibly 13 concentric circular sheets of steel plate, several feet wide, are tightly wrapped around the pressure-vessel shell. These bands are not welded to the shell, and therefore take no longitudinal stress.

The only information available on the John Thompson technique relates to tests carried out recently by the firm on a 5-ft-diameter specimen, 9 ft over ends, which represents to one-tenth scale a 50-ft-diameter reactor. But it is believed that the company has already successfully carried out tests on a 50-ft-diameter reinforced cylindrical specimen to prove the design and manufacturing techniques of a current full-scale design.

The advent of reinforcement for cylindrical vessels is now likely to reverse the current argument in favor of spheres. It had been generally conceded that a cylindrical reactor up to 130-Mw(e) rating showed the best over-all economy in terms of cost per unit sent out, and was inherently more attractive because of construction and installation advantages. But above 150-Mw the sphere became progressively more attractive because of its pressure advantage and the great effect of pressure on heat output. Of the four first-round stations, only AEI–JT's Berkeley station retained the cylinder as used at Calder Hall, the others being spherical.

With reinforcement, a cylindrical vessel not only now enjoys the same theoretical pressure loading as the sphere, but, according to AEI–JT tests, is able in practice to realize 80% of the ideal pressure advantage over a simple cylinder, compared with the 10–15% achieved with a sphere.

Pressure considerations apart, the cylinder still has significant construction and installation advantages over the sphere. These include: (1) cost of the vessel and its shielding is less; (2) fabrication is simpler; (3) headroom over the core is independent of diameter, allowing considerable flexibility in design of charge and discharge equipment; (4) shorter span of the biological shield roof reduces a number of engineering problems.

ROUNDUP

Semi-Autonomy for Safeguards Group Brings Difficulties

In the summer of 1957, the Joint Committee on Atomic Energy sponsored Congressional adoption of a major piece of legislation providing $500-million in federal indemnity for any reactor built in the U. S.—the Price-Anderson Act. Only incidentally, the measure carried this language: "There is hereby established an Advisory Committee on Reactor Safeguards. . . ." The measure also provided that hazard reports of the group "shall be available . . . to the public. . . ."

Thus, in one mighty stroke of the Congressional cutlass, the long-active ACRS was abolished as an internal, AEC-established advisory committee and reconstituted as a "statutory" (i.e. set up by act of Congress), semi-autonomous committee that must report not only to AEC but to Congress and the public as well.

Like the child of a stormy marriage, the reconstituted ACRS is reflecting its birth during a political turmoil—at the height of a bitter quarrel between former AEC Chairman Lewis Strauss and JCAE Democrats. The advisory group's new status grew out of its report to AEC in mid-1956 on the Power Reactor Development Corp.'s Fermi reactor (NU, Sept. '56, R3). After AEC had issued a construction permit, it was revealed—in a report for internal AEC consumption—that ACRS had failed to give the project a clean bill of health.

Though it made no recommendation for or against issuance of a construction permit, ACRS found it "doubtful that sufficient experimental information will be available in time to give assurance of safe operation of this reactor unless the present fast-reactor program of the AEC is amplified and accelerated" and, further, that "it is impossible to say whether or not an accelerated program would give sufficient information to permit safe operation of this reactor at the Lagoona Beach site on the time schedule presently proposed."

Suppression Charged

JCAE Democrats, led by Sen. Clinton Anderson (D-N. M.) and Rep. Chet Holifield (D-Cal.) charged "suppression" of the report by AEC; then, exploiting the opportunity provided the following year by the indemnity bill, reshaped ACRS as an agency whose intended function remains clear and noncontroversial—but whose new status actually is neither.

ACRS Membership

C. Rogers McCullough, *chairman* — *Monsanto Chemical*
Reuel C. Stratton, *vice chairman* — *Travelers Insurance*
Manson Benedict — *M I T*
Harvey Brooks — *Harvard*
Willard P. Conner — *Hercules Powder*
R. L. Doan — *Phillips Petroleum*
Franklin A. Gifford, Jr. — *Weather Bureau Office, Oak Ridge*
Henry W. Newson — *Duke Univ.*
K. R. Osborn — *Allied Chemical and Dye*
D. A. Rogers — *Allied Chemical and Dye*
Leslie Silverman — *Harvard Univ.*
Charles R. Williams — *Liberty Mutual Insurance*
Abel Wolman — *Johns Hopkins Univ.*

Among other things, there is a question in the minds of some AEC officials as to whether ACRS can give its frankest and most valuable advice in reports to AEC that must eventually be published; and there is confusion at AEC and ACRS as to how autonomous Congress expects the group to be. (For example, should it have an independent staff or should it continue to rely for its information on the AEC hazards evaluation staff?)

"AEC has not fully accepted all the implications of the [new] ACRS," an ACRS member told NUCLEONICS. "This organization was not set up as such organizations ordinarily are."

Among the significant changes, he pointed out, are: (1) the reports of ACRS to AEC must be published; and (2) the committee feels that its responsibility in judging nuclear-facility safety has been broadened and deepened ("we dig a little deeper now"). Because of the changes, he said, ACRS deliberately drew AEC's attention to its new status in August by submitting a report, even though tentative, on the Piqua project (NU, Oct. '58, 27); ACRS' tersely worded finding that "the site is not a suitable one" was issued early, he indicated, with the forethought that it would be made public and that such publication would carry unusual weight in any final judgment on the project.

"The committee felt that this letter, at this particular time, would be useful to Mr. McCone [AEC chairman] and the Commission," it was pointed out.

Impliedly Judicial

As an AEC official emphasized, the new ACRS is "primarily advisory but impliedly judicial." This is another way of saying that the five-man AEC may have to share its heretofore sole responsibility for judging nuclear safety. The Fermi case demonstrated that, under the former AEC-ACRS relationship, AEC was free—and, in fact, required by law—to make the final judgment on construction and operation of a nuclear facility. This legal requirement still stands but the Price-Anderson Act appears to have modified it.

"Here is a unique situation," an AEC official observed, "where you have an advisory committee that is almost operating as a separate agency. Apparently Congress did not want a separate agency; rather an advisory group to AEC.

"But publication of ACRS reports is a problem. I would be reluctant to see a separate agency set up. But, on the other hand, I think there can be some substantial improvement in the present arrangement. I think ACRS could tell us much more than it does if the reports were not published."

ACRS Divided

A minority of the 13-man membership of ACRS would like to see the committee given independent status—in effect, completing something Congress only started. However, the majority prefers to continue the close relationship with Clifford K. Beck and his hazards evaluation branch of AEC's Division of Licensing and Regulation.

"It is not clear [from the law] whether the committee should have its own staff and duplicate the work of Beck's staff," a spokesman for the majority view commented. "We do not want to set up a separate staff because it is very hard to get competent technical people—and money. Maybe the Joint Committee's feelings about this will become clearer."

As the arrangement now stands, ACRS gets all of its information through Beck's office; most ACRS matters originate with AEC, then follow-up questions from ACRS are submitted to the applicant or to AEC personnel through Beck. A special ACRS subcommittee is set up when the safety problems of a particular project are unusually tough and, in these instances, the committee deals directly with the applicant in closed meetings where no record is kept.

"We are technical people trying to solve technical problems," explained a committee member. "It is not our function to make a record at these meetings. The fact is that at the present time we take no transcript of the meetings. . . . Also, we try very hard to stay out of anything but technical advice."

Committee Operation

ACRS members are appointed by the Commission for four-year terms, are expected to offer advice to AEC on general safety questions, to review proposed reactor projects (power, test and certain research), and to meet any AEC request for advice on facility safety. Chairman McCullough, who gives about 80% of his time to the committee, conducts the regular bimonthly meetings and special meetings. Meeting preparation is ordinarily handled by McCullough and Richard Graham, one-man staff to the group as full-time technical secretary.

McCullough

Because members come in to Washington from around the country, an attempt is made to report to AEC within a few days after a meeting at which final action is taken. ("When you have the group together, you had better sit down and write a draft of the letter to the Commission while they're still in town. Before they go home the thing is settled. Where they can't agree we defer the question.")

Two aspects of ACRS operation that tend to be underemphasized outside the committee, according to a spokesman, are: (1) in dealing with an applicant, the committee "never tells anyone how to design anything—we merely review what somebody else has designed"; and (2) in addition to meeting AEC requests for advice, the committee "encourages or even requests" research programs in nuclear safety. A committee official said ACRS sponsored much of the safety work connected with the Borax (Boiling Reactor Experiment) and SPERT (Special Power Experimental Reactor Test) series.

"We're a group of idea men on safety," he summed up.

AEC Staff

Working under Harold L. Price, director of licensing and regulation, Clifford Beck has a 16-man hazards evaluation staff; only a deputy to Beck and a meteorologist are needed to bring the staff to full strength. The group includes experts on reactor theory and calculations, stress analysis and pressure shells, boiler codes, heat transfer and chemical engineering ("we have both the physicist type and the practical-engineer type").

The staff also goes outside its own office for advice—to ACRS, of course, and to "quite a list" of consultants. The possibility of decentralizing the operation into AEC field offices has been considered, but the idea has not been adopted because of the big part judgment continues to play in safety evaluation.

"A great deal of judgment in this field continues to be subjective and only one group could maintain the consistency that is necessary," an official stressed. "If you divided this work up in field offices it would be impossible for each of these to have access to the type of people the group here can command."

Over the 30 months of the staff's existence it has reviewed more than 240 projects (or about 100 annually), including reactors, critical facilities, fuel-processing facilities, fuel-element fabrication plants and —most recently—the transportation of radioactive materials. This last project is sponsored jointly by AEC and the Interstate Commerce Commission; AEC is studying critical mass, radiation and thermal aspects, ICC is handling mechanical-integrity aspects.

At any given moment the Branch may have 20–30 projects under active study, with 2 or 3 men assigned to each. Generally, for the large projects, at least 3 and usually more separate actions by the staff are necessary. Reviews are made at the site-selection stage, construction-permit stage, and operating-license stage; also, there may be separate reviews for amendments and design changes at either of the last two stages. For small research and training reactors safety review can be completed in 2–3 weeks; review takes 1–2 months for intermediate reactors; and several months for large test and power reactors.

Procedure

When a license application is filed with the parent division, it is reviewed for adequate evaluation of hazards; if the review is favorable, a memo on the project is sent to ACRS, then a follow-up meeting with ACRS is scheduled. (As mentioned earlier, the applicant may or may not be called before ACRS, depending on the circumstances.)

Beck

If there is a difference of opinion between ACRS and Beck's staff, an attempt is made to work out a common view.

"We do not want to get into a position of direct conflict with the committee," an AEC official declared. "We have not had any divergence of opinion yet as to their judgment of the safety of a situation and our own."

Both groups have three basic responsibilities on project safety: collecting, analyzing and evaluating information. There is this major difference: the hazards evaluation branch serves as staff for both ACRS and AEC in collecting information but serves AEC alone in analyzing and evaluating it.

The value of analysis and evaluation by ACRS, an AEC official said, is the committee's "completely detached viewpoint." The value of review by both groups, he added, is that "it focuses the applicant's attention on safety problems" which might not otherwise be done because of the pressure of other problems of the project.

"The real value of our contribution to this safety problem is just that," he declared. "We're not more expert than the people who are designing the plants, by any means. We don't have the information they have and we don't spend the long hours they do on every detail of it."

Minnesota to Regulate Plant Building, Operation

Minnesota has become the first state to assume control over the construction and operation of nuclear reactors and other nuclear facilities within its borders. The power to say yes or no to nuclear-facility construction and operation in the U. S. had been held exclusively by AEC.

On Dec. 4 the Minnesota State Board of Health adopted a regulation stating that "no reactor shall be operated in this State until the owner has received, or is in possession, of [our written] approval." The rule provides:

- At least 30 days before construction of any reactor or other nuclear facility a hazard report must be filed with the Board. Express approval of the Board is required before any construction start. The Board is free to object to any part of the proposed design "on the ground that the public health may be endangered."
- The Board must be notified not less than 30 days nor more than 60 days before proposed operation of a nuclear facility; no plant can be operated without written consent.

The Elk River reactor, which has been under construction since last summer (NU, Dec. '58, 24), will be subject to both construction and operation review under the rule, said a Board of Health spokesman.

W. R. Lawson, radiation specialist with the Board, said the Board has been dissatisfied with the information it has received on the Elk River reactor and will insist on appraising the design; he pointed out that the "design is not yet final."

Ohio Development

Meanwhile, in Ohio, atomic energy coordinator William Eells has left office and returned to his home. Eells was appointed to the post (first full-time coordinator in a state government) by former Gov. William O'Neill (NU, March '58, 24). By mid-January, new Gov. Michael DiSalle had not committed himself on continuing the post.

The Hole in HRE-2

This remarkable photo of the hole in HRE-2 reactor vessel (NU, Aug. '58, 21) was taken with a 20-ft periscope and a mirror on a hinged arm, in a 100,000 r atmosphere. Hole (between arrows), seen in mirror, is an oval 1 in. wide, 1½-in. long. Cause for failure is still under study

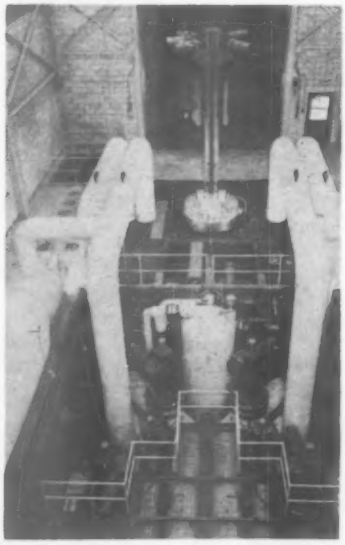
AEC Expects 4 Bids, Gets 11 On Test Reactor Service

No less than 11 proposals were received by AEC for performance of test irradiation services, instead of the four expected (NU, Jan. '59, 24). Bidders were: Aerojet-General; Babcock & Wilcox; Curtiss-Wright; Ford Instrument; General Electric; Industrial Testing Reactors Inc. of Charlotte, N. C.; Purdue University; Republic Aviation; Westinghouse; the Kaiser–ACF–Lockheed–Phillips group; and Texas Engineering Experiment Station of Texas A.&M. College.

Anti-PRDC Unions Still Anti

The three labor unions intervening in the PRDC reactor-safety case have filed more than 30 exceptions to AEC's recent initial decision upholding its construction permit for the Lagoona Beach, Mich., fast breeder (NU, Jan. '59, 23). A union spokesman threatened Federal court action if AEC's final ruling also upholds the permit.

Two Test Reactors, Experimental Unit Observe Noteworthy Milestones



GETR, left, (see p. 27), photographed just before completion, with reactor vessel at lower center. WTR (Westinghouse Test Reactor), is in center, with 95-ton, 33-ft high reactor vessel being tilted into upright position inside vapor container; WTR is to be completed in spring. At right is SPERT-3, with reactor tank top and control-rod drive mechanism visible at top center; small white tank below is pressurizer; at left is one end of one of two heat exchangers

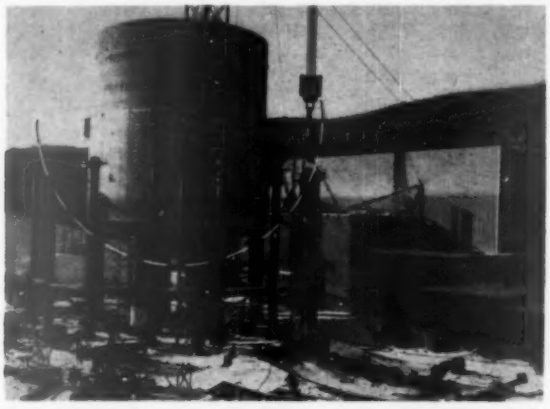
Reactor News

WESTINGHOUSE REACTOR BACKLOGS UP AGAIN

In his annual year-end statement, Westinghouse Board Chairman Gwilym A. Price reported that billings for 1958 are expected to exceed those of the previous year for the fourth consecutive time (NU, March '57, R7; Jan. '58, 28). Atomic backlogs at year's end are expected to be about 30% higher than in 1957, he said, most of it being work for the nuclear navy.

YANKEE STARTS BUILDING SPHERE

"They started to plant an acre of steel plate in the sky at Rowe, Mass.," Yankee Atomic Electric said when Chicago Bridge & Iron began work on the 125-ft dia, 1,800-ton steel sphere 30 ft off the ground that will enclose the Yankee reactor. Yankee engineers pointed out that the $1.5 million elevated sphere (*dotted line*) differs from the other major power reactor enclosures being built in the U. S.; the others are partially buried in the ground, while Yankee's sphere has railroad tracks passing beneath its bottom hatch, is designed for easy access and maintenance. Meanwhile, Westinghouse, builder of the reactor, reported that 70% of the engineering and 10% of the manufacturing for the Yankee plant have



been completed. The project is on schedule—a schedule setting initial operation for late next year. Also, Yankee Atomic, which has been financing construction of its plant by $13-million common stock and loans from member companies, filed its permanent financing plans with the Massachusetts Department of Public Utilities. Capital requirements for building the $50-million plant are estimated at $57-million including first core and cash working capital; this is to be met with $20-million common stock, $20-million first mortgage bonds and $17-million bank borrowings.

GETR COMPLETED, CRITICAL . . .

General Electric's Test Reactor, second privately-financed materials-testing reactor to be undertaken, became the first to be completed. The $4-million, 30-Mw(th) tank-in-a-pool type facility at the Vallecitos Atomic Laboratory went critical Dec. 26; space in its varied irradiation facilities (thermal fluxes up to 2×10^{14}) will be available to private users this month when GETR is brought to full power. GE says the unit will be used primarily, at least at first, to test sample fuel elements.

. . . AND SPERT-3 LIKEWISE

AEC's Special Power Excursion Reactor Test-3 (NU, Aug. '57, 68) achieved criticality Dec. 20 at the National Reactor Testing Station in Idaho. The $3.5-million high-pressure, high-temperature water-moderated and -cooled facility is designed to find basic explanations for reactor behavior under runaway conditions; all operations will be conducted remotely, from a control center half a mile away, "since tests approach reactor destruction." The facility consists of a reactor vessel 4 ft dia × 19 ft high, containing a highly-enriched-uranium core of 60 plate-type, stainless-clad fuel elements and eight control rods carrying fuel sections; a pressurizing tank, and two primary coolant loops with heat exchangers. It is designed for maximum versatility, to give the widest practical range of control over three variables: temperature (68–668° F), pressure (atmospheric to 2,500 psi), and coolant flow rate (0–20,000 gpm, with heat-removal capacity up to 60 Mw over 30 minutes). The unit can thus be used to study conditions of both pressurized- and boiling-water reactors; AEC expects it "to contribute significantly to a better understanding of reactor self-limiting and occasional instability characteristics exhibited in more than 750 excursions in SPERT-1" since that reactor started up in July 1955. SPERT-2, an advance over the open-tank SPERT-1, is still under construction; it will continue the same type of studies but with special emphasis on how various moderators and reflectors, including heavy water, influence reactor behavior. SPERT-3 will study transients starting from different initial conditions of temperature, pressure and coolant flow. Phillips Petroleum designed and is operating SPERT-3; Paul Hardeman Inc. was construction contractor, and Stearns-Rogers Manufacturing Co. executed the detailed design.

BROOKHAVEN DEDICATES MEDICAL CENTER

The $6.5-million medical research center at Brookhaven National Laboratory, begun in mid-1956, was dedicated Dec. 16. It includes a 1-Mw(th) water-moderated and -cooled medical reactor, world's first to be designed specifically for medical use, a 48-bed hospital for research patients, and laboratories. The reactor, to start operation early this year, will deliver a treatment beam with a neutron intensity 50× greater than that of the Brookhaven air-cooled research reactor with which BNL pioneered the radioactive boron treatment for brain tumor.

SCHOOL DAYS . . . AT SHIPPINGPORT

A training program for supervisors of nuclear power plants has been established at the Shippingport Atomic Power Station by AEC, and will be conducted for it by Duquesne Light Co., operator of the PWR. The course, lasting six months, will enroll 25 U. S. and foreign participants every three months for lectures and practical plant work; the first course started Jan. 5. Tuition is $2,000, "to cover associated operating costs." U. S. and foreign organizations engaged in or planning nuclear power projects will be invited by AEC to nominate participants, who will be chosen by a selection board. Entrance requirements include a college engineering or science degree, or equivalent training. The course is believed to be the only one of its kind anywhere offering operational training at a full-scale nuclear plant.

WESTINGHOUSE TO SELL AGN UNITS ABROAD

Westinghouse and Aerojet-General Nucleonics, leading makers of power and research–training reactors respectively, have entered a distribution agreement: Westinghouse will market abroad and export AGN's line of six small reactor types through its world-wide organization.

ROUNDUP

World News

IAEA Disappointed on Fuel Bids . . .

When, responding to IAEA's invitation to bid on supplying three tons of natural U (NU, Jan. '59, 22), Canada offered to furnish the metal free (for resale to Japan at a price "bearing a reasonable relationship to current world price"), IAEA Director-General Sterling Cole termed the offer "an inoculation of encouragement"; he cabled Ottawa that the action "serves as inspiration to the Secretariat and provides a constructive example for future support of the Agency." However, NUCLEONICS learned, IAEA executives are deeply disappointed over the poor response to their call: they had hoped for enough bids so that a wide sampling of prices could be compiled on which to base a "current world market price"—but only three of ten nations invited to bid did so. Not only this: IAEA lobby talk puts main blame on Canada "which seeks to learn about world market prices without showing its own hand." The Belgian and U. S. commercial offers are held to be too far apart to be an earnest basis for computing a world price. Later, IAEA accepted the Canadian offer; resale price to Japan will be $35.50/kg for the 3,000 kg.

. . . Busy Month for IAEA

During December, IAEA: appointed Paul Ruegger of Switzerland, a member of the Hague Permanent Court of Arbitration, chairman of a panel on third-party liability problems in the atomic field; issued its first technical publication, a comprehensive handbook on safe handling of isotopes; postponed implementation of a resolution to compile data on the technology and economics of small and medium-size power reactors and on the needs of underdeveloped countries for nuclear power; completed an agreement for collaboration on common problems with the Food and Agriculture Organization; awarded a study contract to the Univ. of Trieste on a new method of detecting fast neutrons; and saw conclusion of the first session of its expert panel on waste disposal at sea. IAEA will hold an international conference, probably on radiochemistry, in Warsaw this September.

France Opens Door to Euratom Utilities

A new French law authorizes state-owned Electricité de France to enter joint ventures, with private power companies in the other five Euratom countries, to build nuclear power plants in France. EDF must hold at least half the stock in the French corporations jointly set up under the provision; EDF would operate the plants, and the power produced would be split in the same ratio as the stock holdings.

Bone-Marrow Transplants Aid Yugoslav Victims

Transplants of bone marrow, believed to have been carried out on humans for the first time, have apparently saved the lives of five of the six Yugoslavs flown to Paris in October for treatment after a reactor accident at the Boris Kidric Nuclear Energy Institute near Belgrade (NU, Nov. '58, 28; Dec., 26). The Curie Foundation states the five survivors have passed through the most dangerous period and continue to improve; as a result of the marrow transplants, donated by volunteers, their blood chemistry has become practically normal. They are still under close medical supervision, however, not yet being convalescent and the after-effects of marrow transplant not being yet known.

Hamburg A-Ship Group to Buy Reactor

Gesellschaft für Kernenergieverwertung in Schiffbau und Schifffahrt, the Hamburg nuclear ship study group (NU, Nov. '57, 87), is ready to place a preliminary design order for a ship reactor. The decision is expected to be in favor of an organic moderated unit from Interatom, joint subsidiary of Atomics International and the Duisburg firm Demag (NU, Jan. '58, 18). Meanwhile, East Germany has embarked on a nuclear ship project, with a study at a Warnow shipyard for a 1,500-ton vessel.

German Developments

AEG has started to build a 10-watt reactor at its Frankfurt-Niederrad research center, to do neutron flux measurements for the preliminary design order for SKW's 100–150 Mw(e), $26–29-million power plant (NU, Jan. '59, 20). . . . Two research reactors, one each in East and West Germany, reached full power last month: the 50-kw solution type at Frankfurt, and East Germany's first and only reactor, the 2-Mw(th) Russian-supplied water reactor at Rossendorf near Dresden. . . . Farbwerke Höchst also placed its $2-million heavy water plant into full-scale operation (NU, Sept. '57, 31). . . . East Germany and Poland set up a joint agency to monitor airborne radiation along the border and in the Baltic.

Two Commonwealth Reactor Proposals

Mitchell Engineering Ltd. of London has proposed to the government of British Guiana a 21.5-Mw(e), $14-million nuclear power plant to be paid for on the installment plan. The reactor would presumably be a boiling water unit supplied by Mitchell's nuclear partner, AMF Atomics. . . . Australian authorities are understood to be studying the possibility of including a nuclear base-load station as part of the giant $1-billion Snowy Mountains hydroelectric scheme.

British to Simulate Entire Plant

A complete simulation system for a nuclear power plant will be installed for training purposes next July by Elliott Bros. of London at the Berkeley station. The equipment will simulate a graphite-moderated, gas-cooled, natural-U-fueled reactor complete with its steam-raising and power generation side.

AEA Hunting Beryllium in Rhodesia

The U. K. AEA is intensifying its study of beryl deposits in Southern Rhodesia, looking ahead to the beryllium-clad fuel for its advanced gas-cooled reactors. It is carrying out an aerial survey of radioactive deposits, of which two important finds have been made in 1958.

Poles to Start Second A-Center

A second Polish institute for nuclear research will be set up this year in Cracow. EWA, the research reactor at Swierk, has averaged only 65 hr/wk operation due to personnel shortages; new training courses have been instituted.

Italian Items

CNRN, Italy's National Committee for Nuclear Research, has submitted to the government a $75-million, five-year program to bring Italy to the level of other leading European countries in nuclear work, both research and power production . . . The 1.2-Bev electrosynchrotron at Frascati, first nuclear machine designed and built entirely in Italy, has been successfully tested.

News in Brief

Atom's Impact on Local Government Studied

AEC has given a 6-month, $14,860 contract to the American Municipal Assn. for a report on the impact of private atomic energy activities on local government; AEC indicated it was particularly interested in health and safety, fire protection and zoning on local levels. The report will be prepared by the AMA staff, in consultation with Harold Sandbank, an adviser on community and industrial development, Washington, D. C.

AEC Readying Proposed Criteria on Safety

The Hazards Evaluation Branch of AEC's Division of Licensing and Regulation is expected to publish soon the first attempt at setting out criteria for judging the safety of nuclear facilities (as part of a revision of AEC's licensing regulations for production and utilization facilities). The revision was to be reviewed in January by the Advisory Committee on Reactor Safeguards, by representatives of industry, and by other AEC safety advisors before formal publication as a Commission regulation. It would include: (1) more definite procedures for licensing, including review at the site-selection, construction-permit and licensing stages; (2) a comprehensive outline of data required in hazard summary reports; (3) a list of criteria by which projects can be judged, including an indication of acceptable ranges; and (4) an assurance that criteria would not be rigid, to allow for circumstances that may require modifications.

Charges Set for U, Pu Research Use

Base charges of $15/gm U^{235} and $12/gm plutonium have been established by AEC for supply of these materials to U. S. and foreign consumers doing research and development work; the material is leased in this country at 4% annually but can be sold to foreign users whose governments have bilaterals with the U. S.

Low-Cost Radiation Detector for Homes Developed

"Banshee," a miniature radiation warning device for the home that can be made for under $5 has been developed in four months, Tracerlab announces. The unit, using standard components, is plugged into radios—table, portable or auto; it remains inactive until exposed to radioactivity, and then sounds a wailing alarm through the radio loudspeaker—or that of a TV or any audio set. It can be made sensitive to as little as 100 mr/hr, at which point it would emit a popping sound; as concentration increases to 1 r/hr, the warning would build up to a high-pitched wail. Since the sound level rises or falls with the concentration of activity, the device can be used, Tracerlab says, to lead persons out of radiation danger areas. The project arose from AEC Commissioner Willard Libby's call for an inexpensive, dependable device to provide a widespread alarm network for civil defense.

AEC Offers Radiation Grants to Campuses

Adding a little more muscle to its radiation development program, AEC has announced a grants-in-aid program to assist colleges and universities to acquire radiation teaching equipment. Under a similar program in the nuclear-engineering and physical-sciences fields, AEC has awarded more than $10-million to educational institutions; most recently $2,264,965 went to 41 campuses for research reactors and other equipment. AEC did not commit itself to any specific outlay for the campus radiation program but it offered "direct assistance . . . in obtaining demonstration apparatus, student laboratory equipment and training aids needed to offer adequate laboratory course work in radioisotopes." The grants program is designed to increase the scientific manpower qualified to participate in industrial-radiation growth.

Hanford Reactors Get Safety Modifications

In a routine announcement that it was withdrawing its objection to the opening of 105,500 acres of land near the Hanford Works, AEC disclosed last month that it was increasing the containment ability of Hanford's reactors by improving the airtightness of the reactor buildings and stepping up air-filter capacity. The modifications were recommended by the Advisory Committee on Reactor Safeguards. With the improvements, AEC notified the Interior Dept. that the Wahluke Slope area across the Columbia River from Hanford could be developed and settled for farming, though "a small degree of hazard" continues so long as Hanford is active.

AEC Shrinking U-Milling Services

The 600 tons/day uranium-processing mill operated for AEC by National Lead at Monticello, Utah, will be mothballed this summer, according to Allan E. Jones, general manager of the Grand Junction Operations Office. Jones also said AEC was gradually reducing its personnel at Grand Junction under a long-range program to get out of the U-mining and -milling field.

AEC Hears from Texas—on Waste Disposal

AEC's proposal to license a Houston firm for sea disposal of radioactive wastes ran head-on last month into protests from six different Texas sources: Houston's county government (Harris County Commissioners), the Gulf States Marine Commission at Corpus Christi, the Laguna Madre Fisherman's Assn., the Sportsmen's Club of Texas, and two private citizens. A public hearing on the license application of Industrial Waste Disposal Corp. was scheduled at Houston on Jan. 22 before AEC Examiner Samuel Jensch. AEC, which ordered the hearing on its own initiative because none of the protests was a formal petition to intervene, said its staff would appear at the hearing and recommend issuance of the license. Industrial Waste would dispose of wastes in the Gulf of Mexico from a storage point in Houston.

Industry Briefs

AEC has renewed for five years the nonprofit contract of Sandia Corp. for the operation of the Sandia Laboratory, Albuquerque, N. M., and Livermore, Calif. The weapons-research and -development lab has grown to a $73-million facility employing more than 7,700 persons (500 at Livermore) since its creation in 1949. . . . Nuclear Science and Engineering Corp. has been awarded a major radiation-development contract by AEC. The radioisotope contract covers development of a metal-marking technique, a low-level technique for measuring machine-tool wear, an improved gauge for measuring liquid levels in large sealed tanks, and a high efficiency gamma counter. The Commission also extended for another year NSEC's analysis of fallout samples for the AEC Health and Safety Laboratory (NSEC has been participating in the program since 1954). . . . Nuclear Materials and Equipment Corp. has contracted with AGIP-Nucleare, Milan, Italy, to supply 300 aluminum-clad fuel elements for AGIP's Argonaut-type research reactor—now under construction; subcontractor for the cladding is M & C Nuclear.

Westinghouse Sells 5-Mw Water Reactor to GPU

Westinghouse has sold a small—5-Mw(e)—pressurized-water power plant to General Public Utilities Corp. for use as a "hook-on" power source at an existing station on the grid of its Pennsylvania Electric Co. near Saxton, Pa., 25 mi south of Altoona. GPU had been weighing the step since August 1957.

The unit will have one power loop and a loop for experiments to provide data for design of a nuclear superheater. It will be fueled with stainless-clad uranium oxide. Westinghouse's fixed price is $6.25-million; construction schedule allows 30 months from contract signing to criticality, expected in summer 1961.

SNAP-3 Unveiled, Works

Hailed as an important breakthrough on the road to direct conversion, SNAP-3 (NU, Aug. '58, 25), a 5-lb polonium-operated thermocouple device was unveiled by AEC.

With the electrical output of 1,450 lb of batteries, it has a one-year life, 8–10% efficiency, no moving parts.

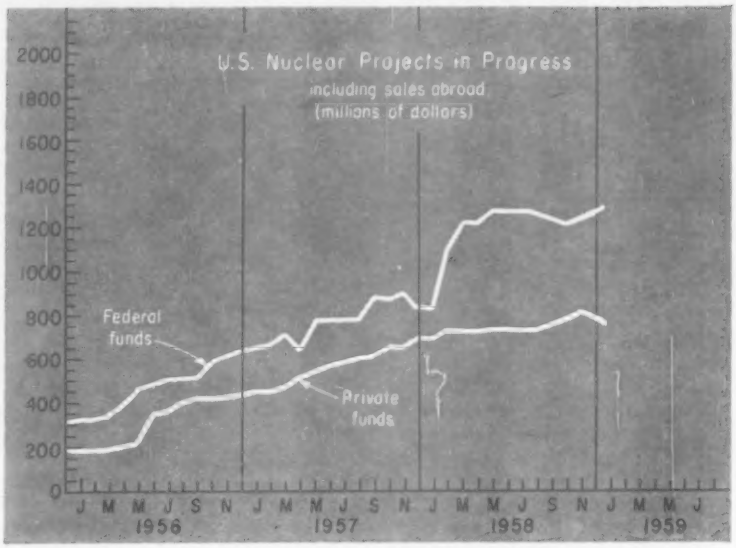
Pentagon Asks More Pu

Reversing long-set policy, the Defense Dept. has asked for a substantial increase in production of plutonium for its weapons program, agreeing with repeated recommendations of the Joint Chiefs of Staff which it had previously been rejecting since 1956 (NU, June '58, 22). The Pentagon is reported to have established long-range Pu requirements for the first time; they are far in excess of present capacity.

Eight More Universities Installing Small Reactors

Eight U. S. universities made news with research-training reactors in the past month. Wyoming bought an Atomics International L-77 solution-type reactor. Wisconsin and Washington received $150,000 grants from AEC toward purchase of small reactors; Washington has selected an Argonaut. Arizona placed its new Triga in operation. Oklahoma announced plans to buy an AGN-211 small pool from Aerojet-General Nucleonics, and to build a simulator, hot lab and isotope lab. Rice Institute, Houston, Tex., is also getting an AGN-211, and obtained an AEC operating license for it. Stanford is negotiating with GE for a 10-kw pool. And Kansas will buy a 10-kw tank-type from Bendix.

NUCLEONICS Statistics of the Month



	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for federal projects ($10³)	4,145	4,196	4,183
Proposed construction, privately-owned ($10³)	0	23,000	3,500
Contracts awarded, private work ($10³)	24,500	0	500
Backlog of private projects ($10⁶)	276	277	247
Isotope Use †—			
Applications for isotope use	706	574	438
Cumulative total of isotope users	4,568	4,426	3,392
ORNL shipments (curies)	5,823	29,053	1,134
Public and private export shipments	377	242	222
Employment †—			
AEC employment	6,790	6,858	6,808
Construction and design contractors' employment	11,039	11,894	11,692
Total operating contractors' employment	103,702	104,307	97,195
Production workers	51,263	51,529	50,294
Research and development employees	46,642	46,639	40,741
Miscellaneous workers	5,797	6,139	6,160

U. S.-built Reactors ‡—

	Operating	Building	Contracted
Power, domestic	1	7	7
Power, for export	0	1	3
Power experiments and pilot plants	7	4	1
Military and naval	6	23	22
Research and test, domestic	51	19	47
Research and test, for export	11	13	10
Total	76	67	90

Foreign-built Reactors ‡—

Power, domestic	8	23	7
Power, for export	0	1	1
Research and test, domestic	28	15	9
Research and test, for export	6	6	1
Total	42	45	18

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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A.D.C. Overall amplifier gain — 1,000. Integral linearity of analog to digital converter is less than $\pm 1\%$ for channels 5 through 128.

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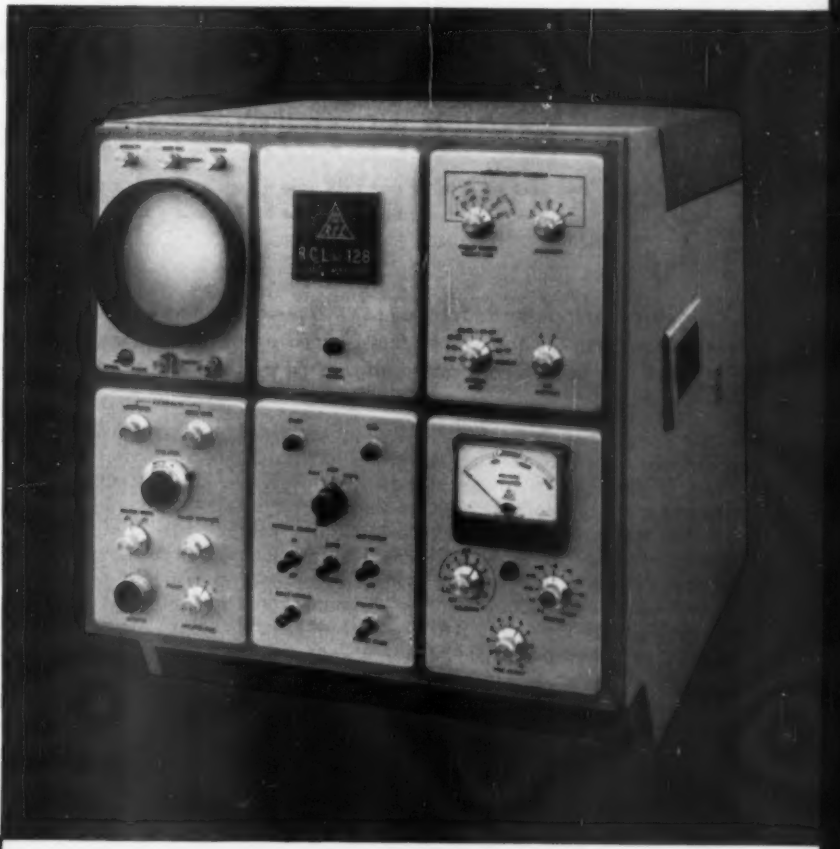

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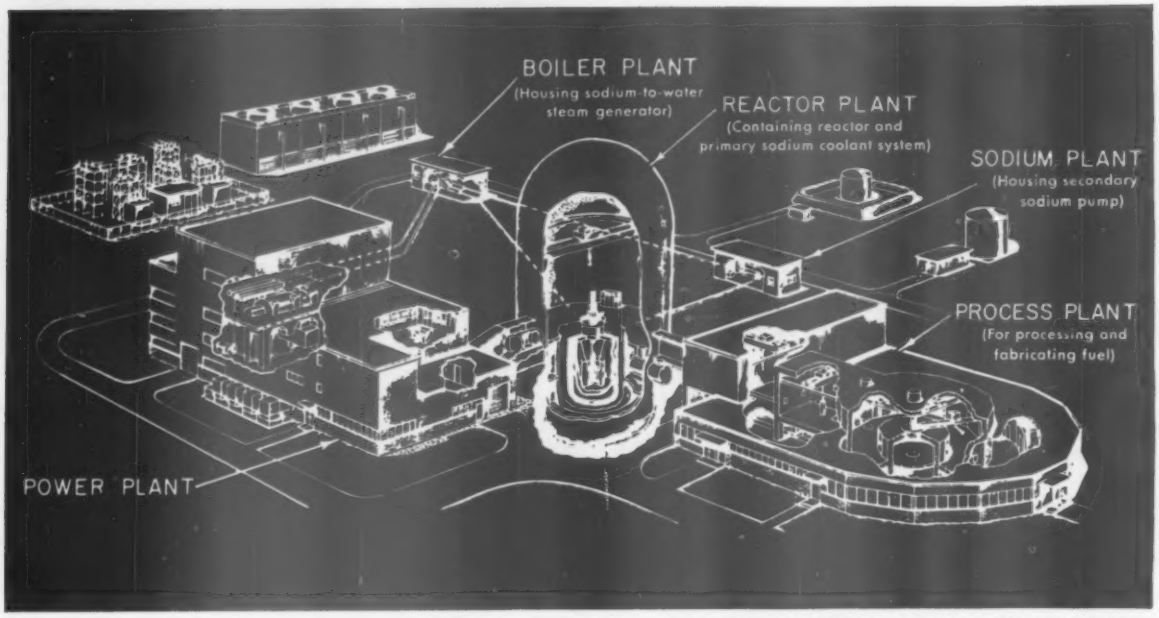

Diagram of EBR-II courtesy Argonne National Laboratory

THIS SODIUM-COOLED REACTOR WILL BE AN IMPORTANT YARDSTICK FOR COMMERCIAL NUCLEAR POWER

Experimental Breeder Reactor-II (EBR-II)—Argonne's sodium-cooled, fast breeder reactor and power plant—will provide performance data that can be directly extrapolated to a commercial plant.

Target completion date for EBR-II, now under construction at Arco, Idaho, is April 1960. In operation, the reactor will produce 62,500 thermal KW, which will be converted to 20,000 electrical KW through a conventional steam cycle.

Tandem liquid sodium heat exchange systems are employed. Sodium in the radioactive primary loop enters the reactor at 700° F. and leaves at 900° F. Sodium in the nonradioactive secondary system enters the heat exchanger at 610° F. and leaves at 880° F. to generate steam at 1250 psig and 850° F.

EBR-II is as near to a prototype central station nuclear power plant as is possible in the design of such an experimental plant. Consequently, it is expected that costs and performance standards for full-size plants can be extrapolated from data developed during its operation. Thus, the economic feasibility of such a reactor can be established.

Operation of EBR-II at high temperatures and its resultant high thermal efficiency are possible because liquid sodium has a high boiling point. Sodium's other advantages as a heat exchange medium include its high thermal conductivity, relatively low melting point, low neutron absorption, high heat transfer rate, ease of pumping, freedom from corrosion in the absence of impurities, and low cost.

For further information on sodium, write for the U.S.I. brochure, "Handling Metallic Sodium on a Plant Scale." If you have special problems, call us for technical service.

FIVE OTHER SODIUM-COOLED REACTORS

- Experimental Breeder Reactor-I (EBR-I) NRTS, Arco, Idaho — fast breeder, sodium-potassium cooled — 15,000 KW (operational)
- Sodium Reactor Experiment (SRE) Santa Susana, Calif. — graphite-moderated — 6,500 KW (operational)
- PRDC Fast Power Reactor, Monroe, Mich.—fast breeder—100,000 KW (under construction)
- Consumers Public Power District, Hallam, Neb.—graphite-moderated —75,000 KW (design stage)
- Chugach Electric Association, Anchorage, Alaska — heavy water-moderated—10,000 KW (development stage)

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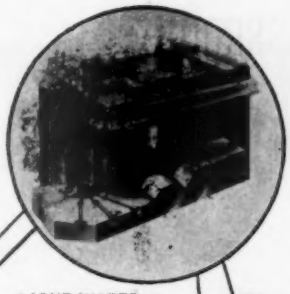
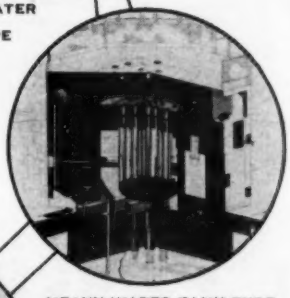
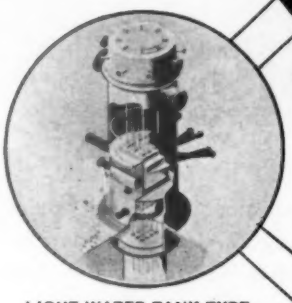


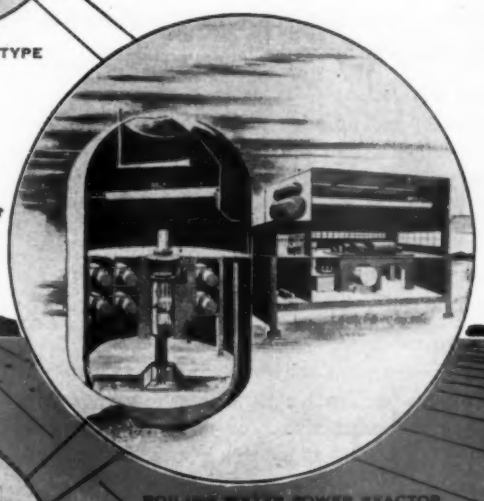
LIGHT WATER POOL TYPE



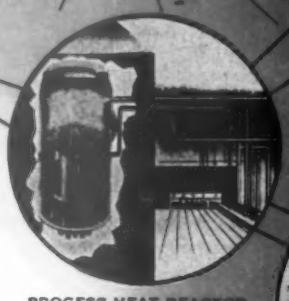
HEAVY WATER TANK TYPE



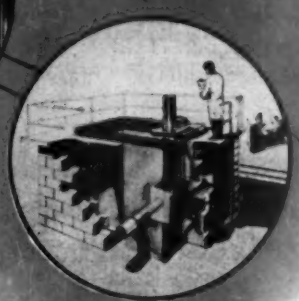
LIGHT WATER TANK TYPE



BOILING WATER POWER REACTOR



PROCESS HEAT REACTOR



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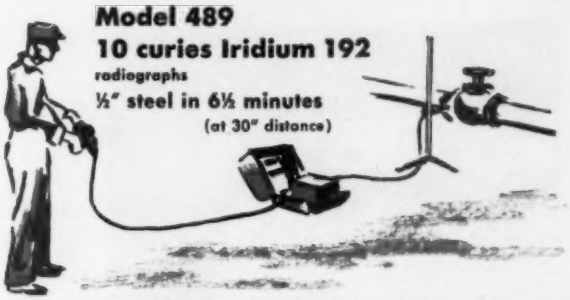
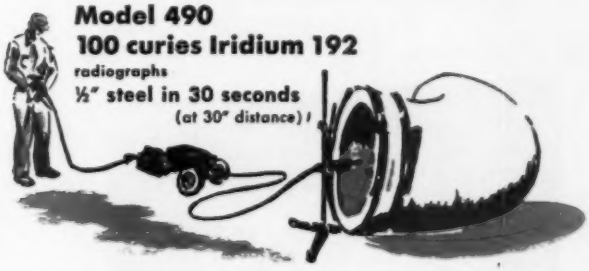


Into a sturdy lightweight fiberglass case no bigger than an overnight bag Tech/Ops has compacted a ready-to-go radiography unit. Complete with a 15 foot control cable and a 14 foot source-guide cable it weighs only 58 lbs.

Its 10 curie Iridium 192 source (5.5 RHM output) will easily radiograph steel sections up to 2" thick in realistic exposure times. Great for pipeline work—it will take the full girth weld of an 8" diameter 1" thick steel pipe in four minutes. Great for radiography in tight spots—the whole works will pass through any opening a man can get through and the snout and guide cable will poke through a 1½" hole.

All this for only $1575.00 complete (without source).

P.S. It will also handle a 50 curie Thulium 170 source if you're inspecting light metals.



Here's a mobile powerhouse—a free wheeling isotope radiography unit that can easily handle the heavy stuff. 100 curies of Iridium 192 (55 RHM output) will radiograph, in one shot, the full girth weld of a 1½" thick steel pipe eight feet in diameter in 6½ minutes.

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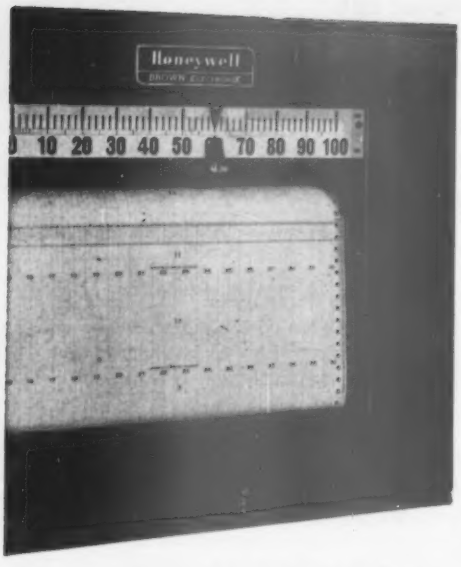

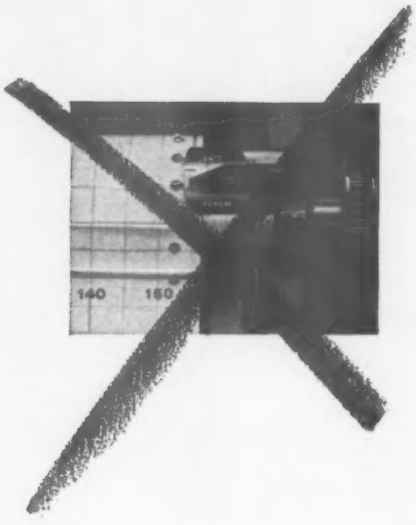

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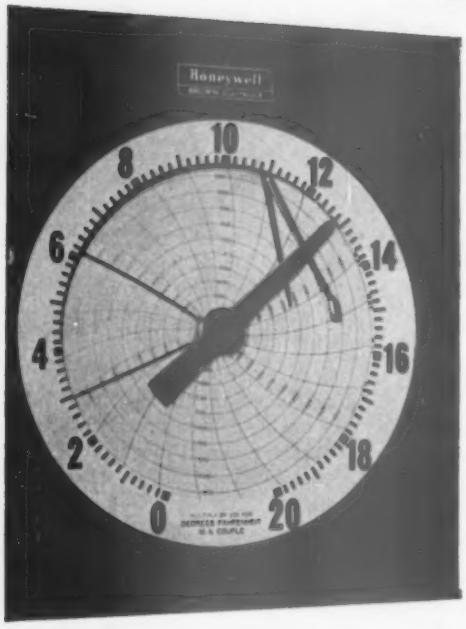

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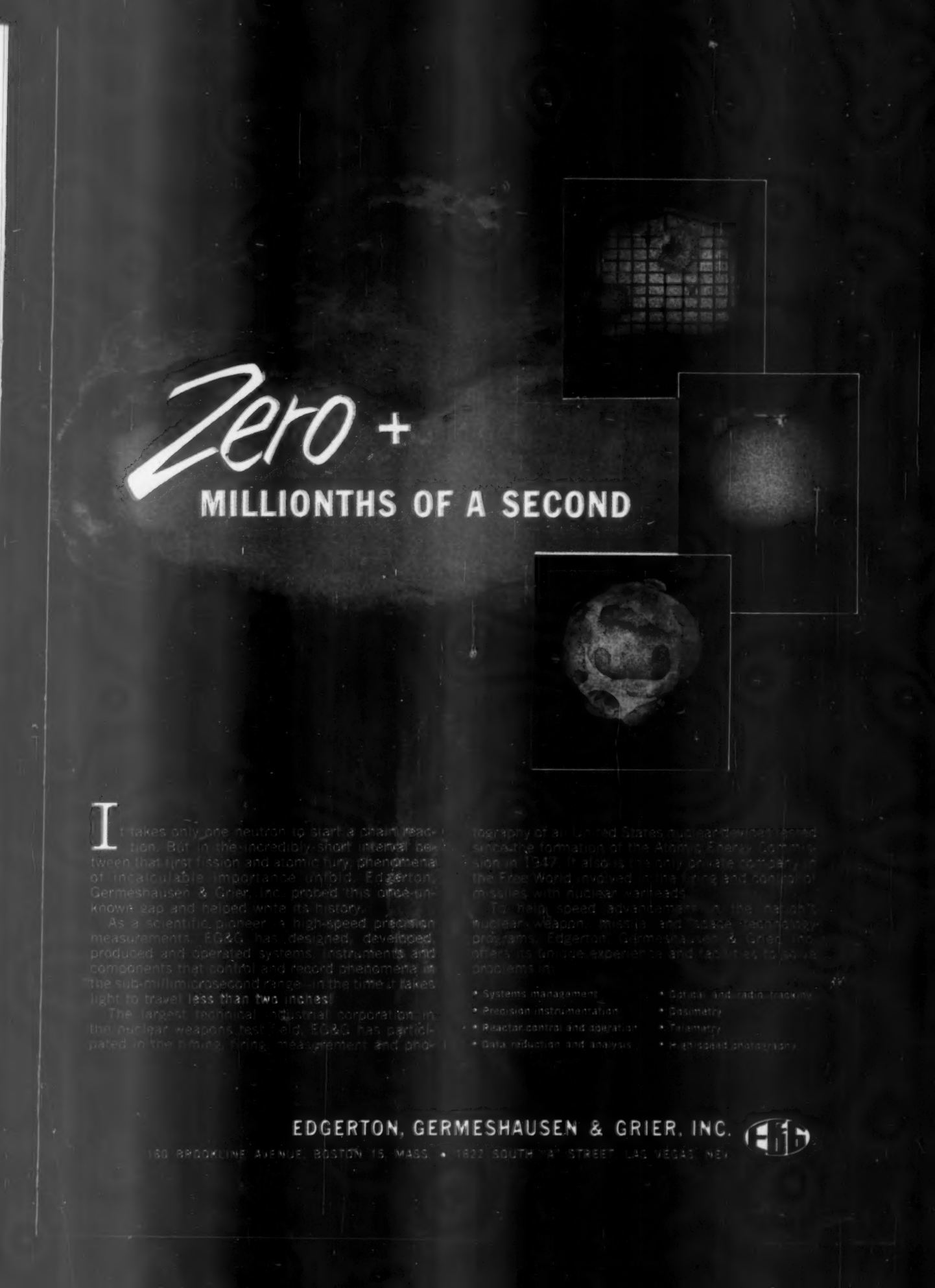
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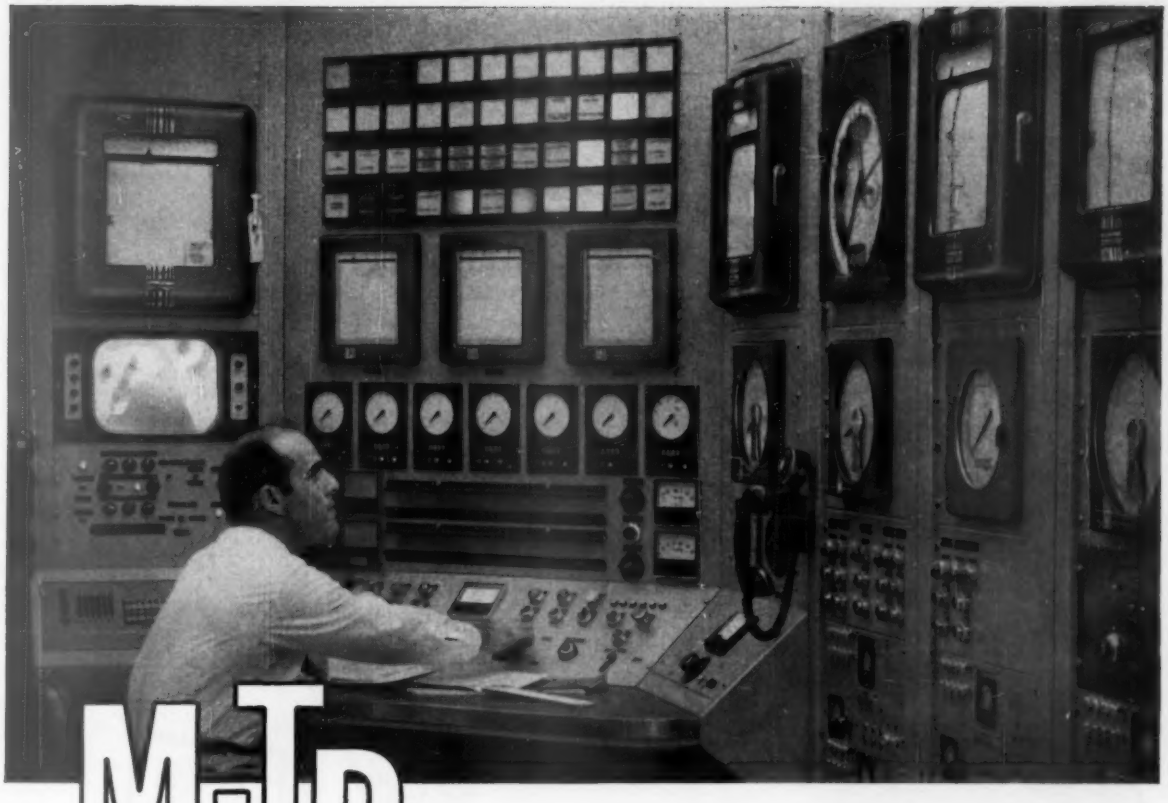

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Organized as Central Utilities Atomic Power Associates, these utilities will share in the research and development costs: Northern States Power Co., Central Electric and Gas Co., Interstate Power Co., Iowa Power and Light Co., Iowa Southern Utilities Co., Madison Gas and Electric Co., Mississippi Valley Public Service Co., Northwestern Public Service Co., Ottertail Power Co., St. Joseph Light and Power Co., Wisconsin Public Service Corp. PIONEER SERVICE & ENGINEERING CO., 231 South La Salle Street, Chicago, Illinois.

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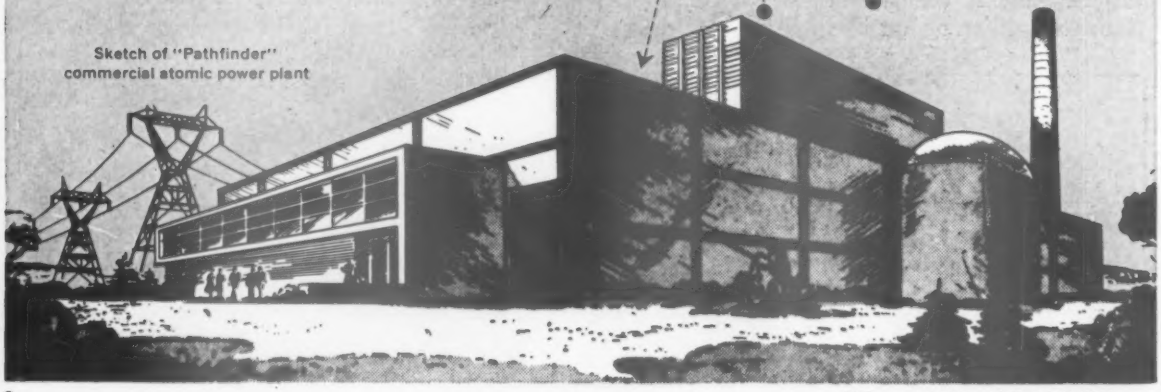
Sketch of "Pathfinder" commercial atomic power plant



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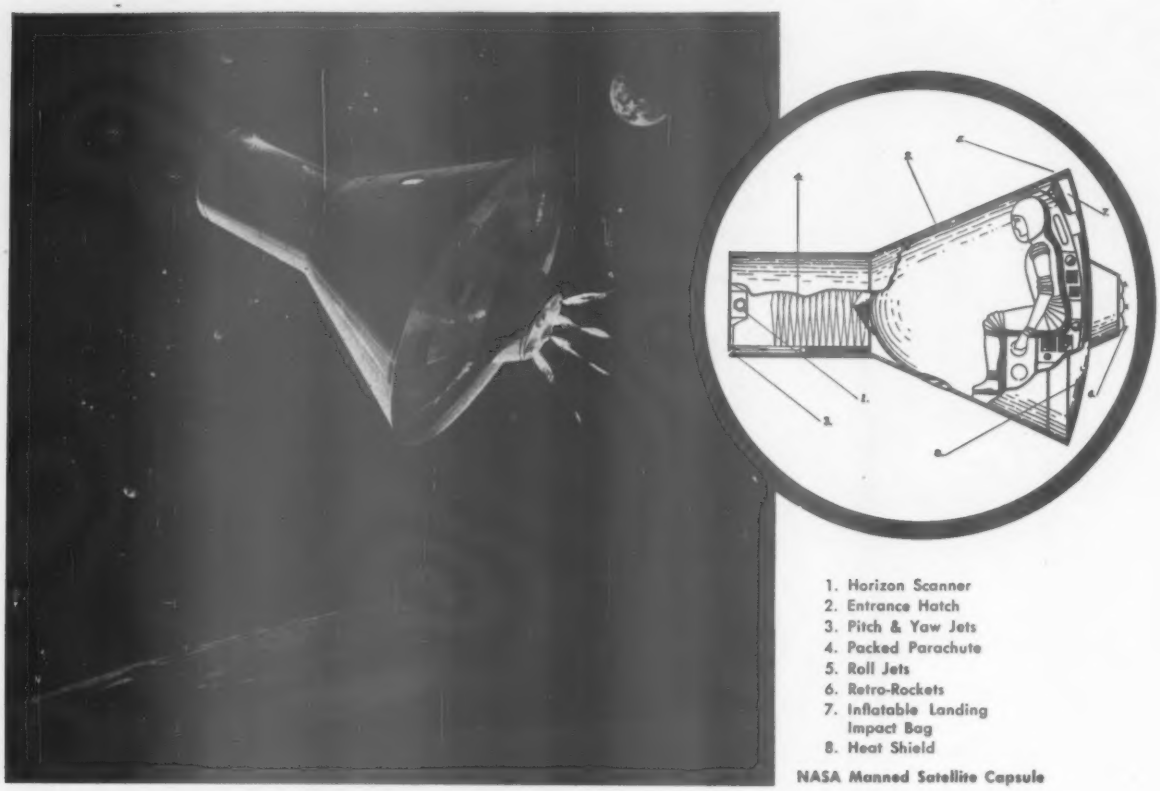

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NASA National Aeronautics and Space Administration

FOR THE NUCLEAR PROGRAM

Several divisions of the Norton Company are making important contributions to the field of nuclear energy. Some of the products that are proving helpful in furthering progress in nuclear energy are:

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- **Diamond cut-off wheels for dicing or wafering — that eliminate waste and assure dimensional accuracy of the costly materials being cut.**

The Norton organization includes an engineering staff experienced in atomic development — available for cooperation where electric furnace products may be of interest. Facilities are available for the production of, or research in, classified items. For further facts, write to NORTON COMPANY, 651 New Bond Street, Worcester 6, Mass.

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Ceramic Fuel Pellets For Nuclear Reactors. Those illustrated are of a thorium-uranium oxide mixture. They are typical of the ceramic fuel element components available in a wide range of compositions made to exact specifications.

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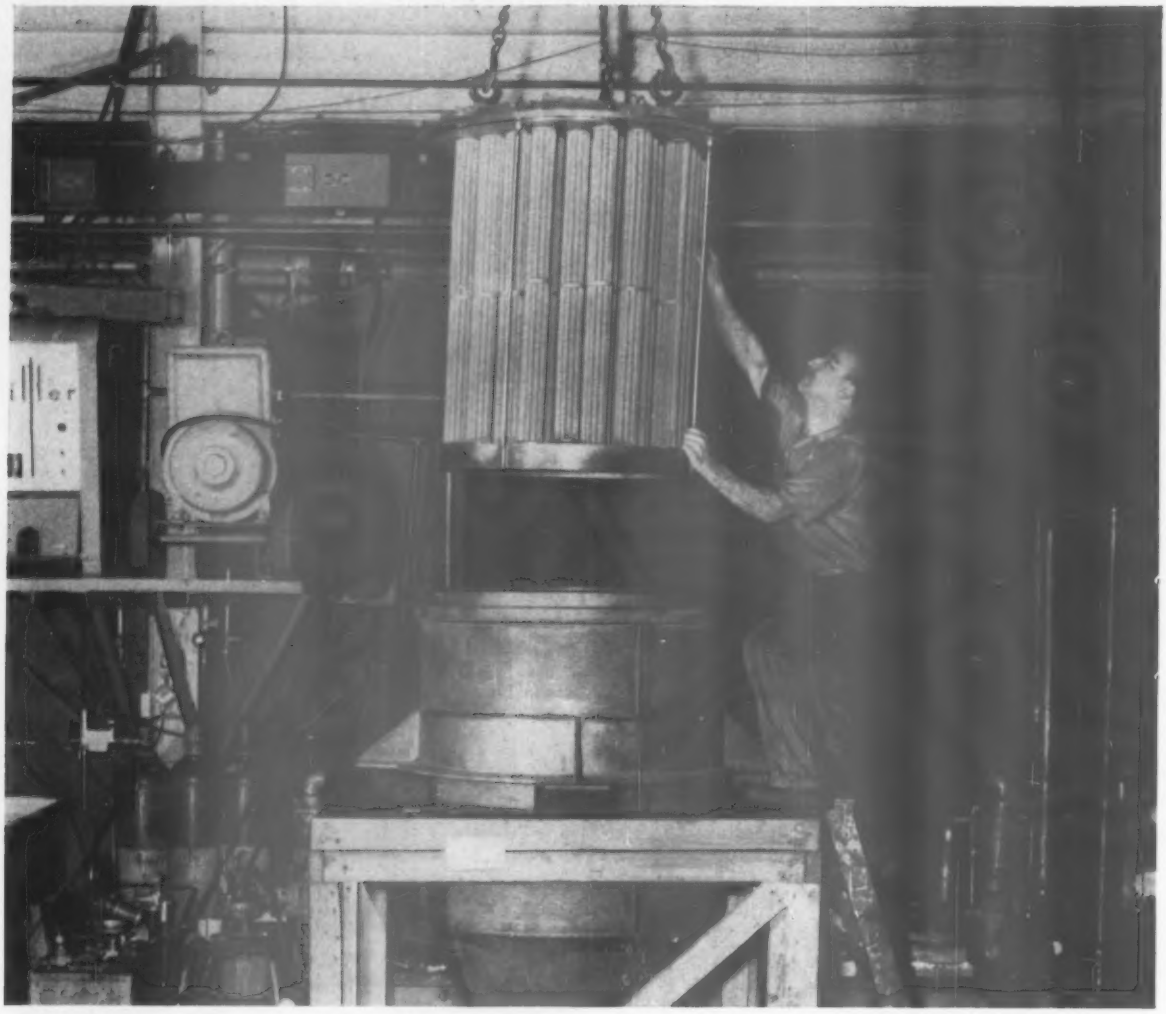

Built to withstand highly corrosive fluorine-containing gases, Monel nickel-copper alloy porous sintered filter elements are lowered into shell. Entire unit, including housing was constructed by Purolator Products, Inc., Rahway, N. J.

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NUCLEONICS
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APPLIED RADIATION
FEBRUARY, 1959

Let's Eliminate the Public-vs-Private-Power Issue

EVER since the Atomic Energy Act of 1954 was passed, there has been a titanic struggle going on in the U. S. on the nature and scope of our atomic power program. The two central questions have been: How big? And, by whom?

Underlying the surface of the debate has been a rather basic ideological difference on public vs. private power. Although this issue is rarely stated in so many words, it is uppermost in the thinking of the protagonists of both points of view.

On one hand, although some of the first money spent on nuclear power by private industry was motivated by an expectation of early economic nuclear power, there is little question today that many private utilities are putting money into nuclear power solely for ideological reasons.

On the other hand, there is also little question that behind some of the impatience that some of the advocates of big government nuclear power programs have with industry is their basic feeling that it would be better anyway for the government to develop nuclear power.

THEIR disclaimers to the contrary, both sides convey the impression that they would like to use nuclear power to shift the relationship between public and private power in the U. S.

It is inevitable that all the arguments on both sides will be dragged out again in the upcoming Congressional debate on nuclear power policies. And, it is inevitable that at center stage will be the matter of the cancellation of the Pennsylvania Advanced Reactor project (see NU, Jan. '59, p. 28, and p. 61, this issue), which was dropped by Pennsylvania Power and Light and Westinghouse because they decided a prototype was necessary before building a full-scale plant.

It should be recognized that the PAR project was conceived privately and financed privately. It did not forestall any project that might have been undertaken by the government. For $9-million of private money, the country learned a great deal about the concept being studied.

DESPITE these facts, the PAR case highlights the problem faced by the U. S. on how to achieve economic nuclear power in the shortest time and the most orderly fashion. (The recent study by the staff of the Joint Committee on Atomic Energy emphasizes the general agreement that now exists on the need to get ahead with the job.) The basic issue still is the public vs. private power controversy. If this issue can be eliminated, the real decisions that must be made can be faced with greater clarity.

With this in mind, we recommend the following amendments to the Atomic Energy Act:

1. All electricity-producing experimental nuclear power reactors paid for in entirety by AEC shall be built at existing AEC sites.
2. AEC shall build no electricity-producing nuclear reactors that would be reasonably expected to produce power from the first core at a cost less than 125% of the cost of power from a new conventional plant of similar size in the highest-cost geographic area in the U. S. in which a plant of its size might be built on a commercial basis.
3. At any one time, the electricity produced from nuclear reactors at an AEC site shall not exceed the electric-power requirements of that site. This may require that at any one time not all experimental power reactors in operation at a site will have generators connected.

There is little question that these amendments would impose some inconveniences and limitations on AEC. But the benefits to be gained would be considerable. Even with the public preference proviso (Sec. 44) still in the law, the basic issue will essentially have been eliminated. Then the common goal for all will be: economic nuclear power.

Jerome D. Luntz

The Army Reactor Program

U. S. military installations overseas now number in the hundreds. In size they range from small radar and signal stations with power demands of a few hundred kilowatts to large industrial complexes such as major air and naval bases requiring 20 Mw(e) or more. At present, diesel or gasoline units supply these bases with the necessary electric power and space heating. The replacement of these fossil-fueled units with suitable nuclear-reactor-power sources would result in major logistic and economic advantages.

Possible customers for nuclear reactors are the more than 60 stations of the early warning radar network (see figure below) that lies north of the 55th parallel on the North American continent. In addition, there are several military installations in Alaska, Antarctica and other remote locations where logistics problems already outweigh the cost factor. In the longer range, the military wants to apply nuclear power anywhere it will deliver better performance than conventional power.

In the pages that follow NUCLEONICS, with the cooperation of the Army Reactors Branch of the AEC, describes the over-all Army reactor program (p. 47), the Army package power reactors (p. 50), and the gas-cooled reactor program (p. 52). Finally, facing p. 54, there is a foldout description of the latest Army reactor to go critical—the Argonne Low Power Reactor.

ARCTIC RADAR NETWORK STATIONS, now powered by diesel fuel, will be among the prospective customers for Army's ALPR-type power units. Insert shows proposed ALPR-Dew line station package (FIG. 1)

THE ARMY NUCLEAR POWER PROGRAM (ANPP), unsung member of the U. S. reactor development family, has quietly established itself as the major force in small-reactor technology. The pendulum of progress has swung the program from development to application for two of the program's reactors, Army Package Power Reactor and Argonne Low Power Reactor, for within a year the Pentagon will enter the reactor market as an increasingly important customer for construction of nuclear plants outside the continental United States.

Beyond APPR and ALPR another five reactor projects are in various stages of development as the Pentagon and AEC proceed toward perfection of a small-reactor family capable of meeting a variety of military requirements—stationary, semimobile, mobile and propulsion—in the range several hundred to 40,000 kw.

The ANPP Family

Reactors developed or under development show the scope of military potential:

Operating. The 2-Mw(e) Army Package Power Reactor (APPR-1) at Ft. Belvoir, Va., and the Argonne Low Power Reactor (ALPR) at the National Reactor Testing Station, Idaho (NU, Sept. '58, 154).

Building. The Gas-Cooled Reactor Experiment (GCRE) at NRTS and the associated closed-cycle-turbine facility at Ft. Belvoir (NU, May '58, 17). At Ft. Greely, Alaska, APPR-1a, a modified version of APPR-1, will deliver twice the power from the same size core and promises a longer core life than APPR-1.

Projected. A pressurized-water, modular-type reactor for the Air Force which will be let shortly by the AEC under a design, development, and construction contract for completion by mid-1961 [1 Mw(e) and 2 Mw(th) (NU, Nov. '58, 25)]; a barge- or pier-type reactor for which a feasibility study has just been completed by Gibbs & Hill, naval architects, and Moran, Proctor, Mueser & Rutledge, consulting engineers; a compact reactor of up to 2 Mw(e) for which studies are now being completed by Curtiss-Wright, General Electric and the team General Motors/Nuclear Development Corp. of America (NU, Feb. '58, 24); and a trailer-mounted reactor which, it is hoped, will grow out of the work on the gas-cooled reactor.

Finally, AEC and the Engineers Corps have awarded Alco Products a preliminary design contract for an APPR-type reactor of even higher output and longer life than APPR-1a.

The ultimate ANPP objective is to get practical field plants into military service. The 1-Mw(th), 2-Mw(e) APPR-1a under construction at Ft. Greely is the first field plant. No field plant was scheduled this fiscal year but a program of overseas construction is to begin in fiscal year 1960, continuing thereafter on an upward curve (NU, Nov. '58, 25). ANPP officials see their practical power ceiling for reactor development as 10 Mw(e). Military installations have requirements running up to 40 Mw(e) but ANPP officials are relying on the AEC and private industry to develop concepts beyond 10 Mw(e) that would be available for military purchase.

Future Army Reactor Family

Reactor Type	*Reactor Power [kw(e)]*
Fixed Plants	
Improved ALPR	300–1,000
Improved APPR	6,000
Plants developed within civilian power program	>10,000
Semimobile Plants	
Modular design ALPR	300–1,000
AEC-AF modular design	1,000–2,000
Mobile Plants	
Trailer-mounted gas-cooled reactor	300–500
Compact reactor plant (possible land-vehicle power source)	2,000–3,000
Barge-mounted reactor (APPR or other)	~10,000

Military Advantages

For many remote military bases, especially for arctic installations, the fossil fuel supply accounts for a large part (as much as 70–80%) of the logistic effort. With nuclear power sources this effort would be drastically reduced. Each electrical megawatt of installed nuclear-power-plant capacity means an annual logistical saving of up to 20,000 barrels of oil. In terms of shipping, a 20,000-kw(e) nuclear plant would each year save the equivalent of some 700 railroad coal cars or 8–12 oil tankers.

Since logistic capability is a major limiting factor in modern warfare, the use of nuclear powered units in the field could greatly extend our total military capability. Apart from reducing logistic effort per se, nuclear power would increase the reliability and effectiveness of military operations by making field commanders less dependent on vulnerable supply lines. A nuclear-powered base could operate for a period of years without fuel resupply; to do the same thing a diesel station would require very large (and therefore vulnerable) fuel-storage facilities.

Military Requirements

In terms of engineering development the uses proposed for land-based nuclear power plants fall roughly into two categories: a) those that can employ versions of already existing reactor systems such as the APPR and ALPR and b) those that require the development of radically different reactor concepts beyond the reach of present technology. Power plant units for overseas semipermanent installations such as Dew-line radar stations fall into the first category while trailer-portable power supplies and nuclear land vehicles are examples of the second.

Fixed stations. Requirements for fixed field plants of proved performance and maximum dependability will be met by improved versions of APPR-1 and ALPR, both considered ready for field location now. Where on-site construction costs or the need for

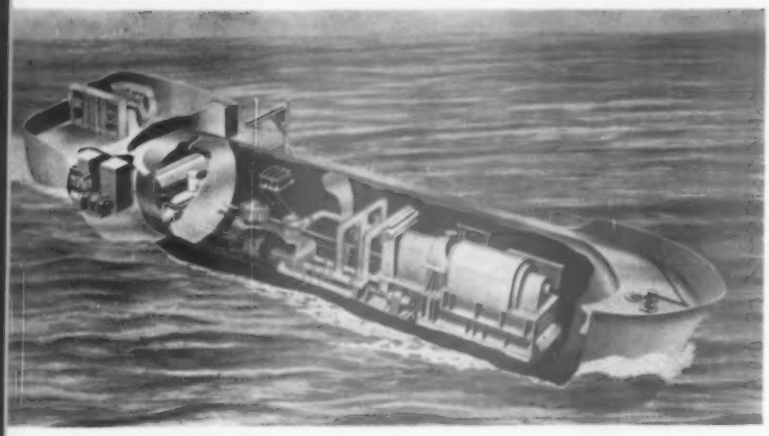


FIG. 2. Barge-mounted reactor would serve as mobile power source with outputs up to 10 Ww(e) output

relocation rules out fixed plants, the need will be filled by highly packaged, semimobile, pressurized-water plants of the type ordered by the Air Force for mid-1961 delivery.

The development effort on the APPR and ALPR-type systems is aimed at transforming the first working prototypes into pieces of dependable military hardware which can be transported, assembled and operated using a minimum of time, manpower and skill.

Both the number and size of the prefabricated modules that comprise the system must be reduced as far as possible. Assembly in the field should be possible with ordinary skills and tools.

Plant reliability is probably even more important in military than in commercial nuclear plants. Since most military systems will have only one, or at most a few, reactor units a reactor failure in this type of system is much more serious than for a single unit in a large multiple-plant commercial power system. On the other hand reliability is more difficult to achieve since the environmental conditions are typically extreme and the opportunity for maintenance often limited.

Also modern military electronic equipment requires electrical power of extremely high quality. Therefore, military plants powering such equipment must meet severe restrictions on voltage and frequency variations under both steady and fluctuating loads.

Plant simplicity is of vital importance if the plant is to be operated and maintained by a small crew with a minimum of specialized skills. For the relatively small plants being considered for military use a crew of even moderate size can quickly lead to excessive power costs. For example the labor costs for a crew of 8 men operating a 200-kw(e) plant would come to 40–50 mills/kwh. The demands on the military's economic and manpower resources would be even greater if any of these men required highly expert training. Finally the additional logistic effort required to support large operating crews could very well cancel out the logistic advantage hoped for in replacing a remote diesel unit with a nuclear plant.

In this regard experience so far with APPR-1 indicates that a specially qualified crew of 14–20 (1–2 officers and 13–18 enlisted technicians) will be able to keep a reactor of this type in continuous service at a remote installation. The lower figure is roughly the crew size used on conventional plants of similar output.

Mobile plants. In addition to fixed plants, mobile power sources would be of great value in field operations. These might range from small trailer-mounted units with outputs of a few hundred kw(e) up to reactors with outputs of several thousand kw(e) that could support transient bases or weapons systems or propel land-vehicles.

Accordingly the Army program includes a long-range effort (see p. 52) to develop a high-temperature gas-cooled reactor coupled together with a closed-cycle gas turbine to form a mobile unit. Compared with a water-cooled system, the highly enriched gas-cooled concept has the advantages of lighter weight, fewer components and no need for an environmental water supply. When developed the unit would be small enough to be trailer-mounted and would have power output in the range of several hundred kw(e).

Another type of mobile plant would be mounted on a barge. Such plants could be built with outputs sufficient to furnish large blocks of electric power for strategic power reserves and

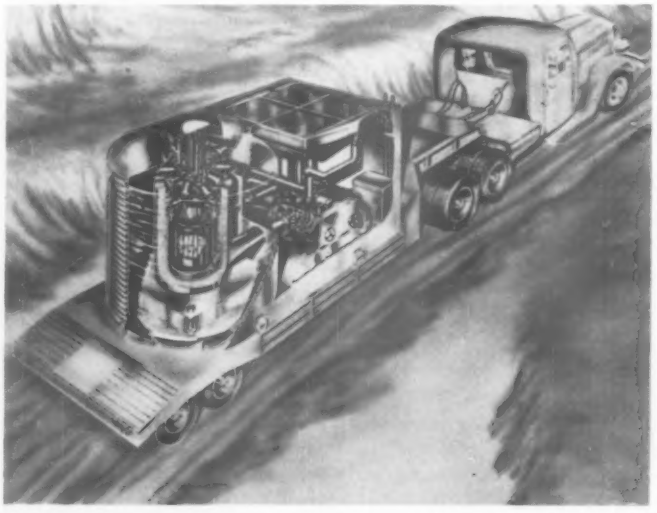


FIG. 3. Trailer-mounted power unit is ultimate objective of Army's gas-cooled reactor program

to provide mobile power sources for emergency use both overseas and in the United States.

Finally, studies have shown that it may be possible to substitute a nuclear power plant for the conventional diesel-electric unit in a logistical cargo carrier (SNO-Train) now being developed by the Transportation Corps.

Military Economics

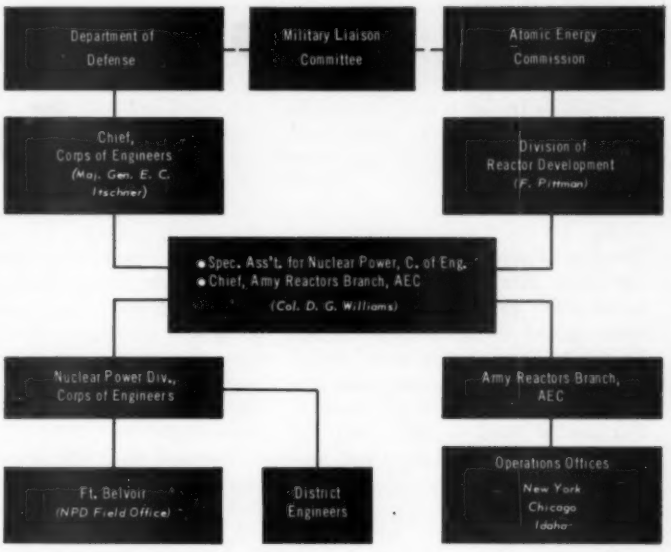
Field tests such as the Ft. Greely, Alaska, project (see p. 51) should soon demonstrate conclusively that APPR and ALPR reactor plants can be used to strategic advantage. Widespread adoption by the military will then become a question of economics. Like commercial nuclear plants, military nuclear power sources will have an initial cost greater than that of the conventional power sources they are to replace.

This problem is particularly severe in Army applications because the majority of these units will be relatively small, probably averaging less than 5 Mw. Moreover the cost of assembling the military plants at remote locations is abnormally high—often 2–4 times the cost of similar construction in the U. S.

On the other hand since its operating expenses are expected to be much lower than those of fossil-fueled units, a reactor in a remote location can justify its higher investment cost provided it is kept in service for a long enough time. Thus the cost of a nuclear plant need only be reduced to the point where the total cost of power generated over the projected military lifetime begins to approach that for present installations.

For instance, APPR-1 will operate for approximately two years on its present fuel loading, assuming an average plant factor of 70%. A modern diesel-fueled plant operating under the same conditions over the same period of time would consume approximately 2,280,000 gallons (or 54,400 barrels) of high-grade diesel oil. The delivered cost of this fuel can be as high as $1–$2 per gallon at remote sites supplied by airlift. Thus economic studies indicate that even with current high initial costs, APPR-type plants are competitive with conventionally fueled plants over a period of several years' operation in some remote areas.

Organization Chart of the Army Nuclear Power Program


Department of Defense
Military Liaison Committee
Atomic Energy Commission
Chief, Corps of Engineers (Maj. Gen. E. C. Itschner)
Division of Reactor Development (F. Pittman)
• Spec. Ass't. for Nuclear Power, C. of Eng.
• Chief, Army Reactors Branch, AEC
(Col. D. G. Williams)
Nuclear Power Div., Corps of Engineers
Army Reactors Branch, AEC
Ft. Belvoir (NPD Field Office)
District Engineers
Operations Offices
New York
Chicago
Idaho

ANPP's organization, already complicated to some extent by the double chain-of-command that characterizes all military reactor programs, is further complicated by the fact that it is misnamed. Despite the "Army" in its title, the program is conducted to meet not only the Army's reactor requirements but those of the Navy and Air Force as well.

Program director is Col. Donald G. Williams, Chief, AEC Army Reactors Branch, and Special Assistant for Nuclear Power to the Chief, Army Corps of Engineers. His AEC/Corps of Engineers operation is charged with the development of ground reactors (heat and electricity) for all military services and of special-purpose reactors (barge, etc.). Virtually the only military reactors outside his jurisdiction are those for propulsion of warships, aircraft and rockets.

The nuclear power requirements of the Army, Air Force or Navy are funneled through the Secretary of Defense, to the Secretary of the Army, to the Chief of Engineers, and finally to Williams. Requests for development of specific reactor concepts are forwarded by the Secretary of Defense to the AEC where they again reach Williams through that chain-of-command. To permit day-to-day liaison among the services, Air Force and Navy personnel are assigned to the Army Reactors Branch.

When a reactor concept has been developed to the point of field-construction readiness, the Williams team withdraws in favor of the sponsoring service (except for consultative duty). Construction of field plants—for example, the Ft. Greely, Alaska, reactor (NU, July '58, 25)—is handled through normal procurement channels, rather than through AEC. As an Army reactor project, Ft. Greely is being supervised by the Corps of Engineers under contract with private industry; the Corps may also be construction agent for AF ground-reactor projects. For Navy projects, the Bureau of Yards and Docks would probably have construction jurisdiction.

THE ARMY REACTOR PROGRAM

APPR-1 Operating Experience

THE ARMY PACKAGE POWER REACTOR-1 (APPR-1) plant (see NU, Aug. '57, facing p. 60) was the first to be developed in the Army Nuclear Power Program. Construction began in October, 1955, and was completed less than 18 months later. It first went on the line in April of 1957, and, by November 1, 1958, the plant had produced 15,332 Mwh(e).

Operating History

After the core was loaded, a test series was run to compare the reactor's operating characteristics with the design calculations. During these tests, the steam generator failed to deliver superheated steam as called for in the design because of trouble in the moisture separator. The pressure drop across the separator was higher than it should have been, with the result that the drain was drawing water up to the dry-steam side of the separator. A three-week shutdown was required to cut the top out of the steam generator and replace the separator with another type.

700-hr test. Prior to Army acceptance, the plant was required to operate at loads between 10 and 100% of capacity for 700 hr, with a maximum permissible shutdown time of 40 hr. The test was completed with only 7 hr, 28 min of shutdown. The reactor was scrammed three times because of electrical disturbances in the distribution net that caused the sensitive scram circuits to trip. A fourth shutdown was required to adjust the calibration of the liquid level in the shell side of the steam generator.

During the 700-hr test, reactor power level followed load changes better than expected. The APPR-1 can undergo a complete loss of load without causing a scram—the reactor drives itself subcritical and stays that way until the power level equals the system heat loss. Also, the reactor can follow a load increase as fast as the turbine will allow, without adjustment of the control rods.

Six-month test. The plant was next operated at full power each month for 21 days and then at varying loads from zero to full load to train the Army, Navy and Air Force personnel serving at the plant. During this six-month test, only one minor failure occurred. The gasket on a rupture disc developed a leak so that a small amount of primary coolant accumulated on the floor of the vapor container. The rupture disc was replaced by a relief valve and the flange replaced by a welded connection. Cleanup required only that the floor and lower portion of the wall be swabbed and washed down with fresh water.

The only significant incident that has occurred since the completion of the six-month test was a leak caused by the failure of a spring in the pressurizer relief valve. Repair was easily accomplished and cleanup was as before. By July 1, 1958, the plant had generated 12,223 Mwh. An analysis of the operating history of the plant shows that it was on the line 226 days, 44 days were spent in training exercises and down time totaled 73 days. During the time devoted to training, the plant was operated at various power levels but was not on the line.

Component Performance

Mechanical components. Considerable difficulty has been encountered with the various pumps, with one notable exception—the primary canned-motor pumps. The makeup pumps required considerable attention because the stainless-steel plungers wore excessively, resulting in leakage through the packing, and had to be replaced. Two of the stainless plungers were replaced with ones of Hastelloy and two with ceramic plungers. Both replacements have performed satisfactorily to date.

The time required to cool the primary system down from 450° to 212° F was found to be 30 hr. The reason for this slow cooldown was that the pressurizer, being a dead leg in the system, did not have sufficient circulation and, being well insulated, took a long time to cool down. Recently, a separate line from the primary piping to the top of the pressurizer has been installed to force circulation through the pressurizer. This modification is expected to cut the cooldown time to 12 hr.

Instrumentation. The biggest day-to-day problem has been the reliability of the instrumentation. The signal strengths from the ion chambers are so low that the amplifiers must be operated at high gain to develop sufficient signal strength for indication and control purposes. Because of this, electron tubes must be replaced at an alarming rate. These replaced tubes could perform satisfactorily in conventional electronic devices, but they cannot remain in a reactor-control circuit once their noise level picks up. Well over three hundred tubes were replaced in less than a year of operation, although only a few tubes actually failed. The use of transistors is being evaluated as a means of alleviating this problem.

Noise and transients have caused

numerous false period scrams. This problem has been partially solved by the installation of filters and the correction of improper sealing in the mineral-insulated wire terminations.

The original BF_3 counter tubes failed frequently because of the high flux during power operations and had to be replaced with those of another manufacturer. Several fission chambers also have been replaced because of high internal noise level caused by residual radioactivity.

Operating Problems

Water purity. In the secondary system, maintaining water purity is a problem. The type-304 stainless-steel tubes in the steam generator are very susceptible to chloride stress corrosion, and there is no way of inspecting them. The chloride concentration is monitored by recording conductivity cells in the evaporator and secondary-system blowdown water and by daily laboratory analysis. To date, the chloride content has been controlled to 0.1 ppm by maintaining a blowdown rate of 0.2–0.5 gpm.

Hydrazine is used for oxygen control in the secondary system. After several months of operation, however, it was found that the air ejector was maintaining the oxygen level at the range of 0.01–0.04 ppm and that the hydrazine was not effective. It was later determined that the hydrazine did not react with the oxygen under APPR-1 operating conditions. Tests indicate that sodium sulfite would be more effective than hydrazine, and its use more desirable because it does not add ammonia to the system. However, it would not be possible to monitor the chloride concentration by conductivity readings of the blowdown because of solids contributed by the Na_2SO_3.

Activity buildup. Operating experience to date has shown that long-lived nuclides tend to build up on the surfaces of the primary system. This buildup may reach magnitudes that could seriously hinder maintenance work on primary-system components—present information indicates that the activity level inside the steam generator, on the primary side of the tube sheet, is about 2.5 r/hr. The stainless-steel-clad core components in the high-flux zone are adding the major portion of the activated corrosion products to the system. The main nuclides that contribute to this activity are Co^{60}, Co^{58}, Fe^{59}, Mn^{54} and Cr^{51}.

A program is underway to develop a decontamination technique to reduce the activity in the steam generator to allow maintenance work. Also, the second core of APPR-1 will use a special, low-cobalt stainless-steel (304) cladding. It is hoped that this will reduce the rate of buildup of Co^{60}.

APPR-1a—the Second Member of the Family

The only significant difference in design between APPR-1, the first of the family, and APPR-1a is that the second reactor is rated at twice the thermal output of the first even though they both have the same core loading. This is accomplished by increasing the primary-coolant flow rate from 4,000 gpm in APPR-1 to 7,150 gpm in APPR-1a. Although both designs were based on providing electrical power and space heat, the entire output of APPR-1 is used to produce electricity because Fort Belvoir, the site of the prototype, has no need for additional space heat.

APPR-1a will provide both power and heat for the Army post at Fort Greely, Alaska, which is about 85 air miles southeast of Fairbanks. Fort Greely was selected as the site for the first field plant because it is in a location that will provide an operating test of the plant under extreme cold weather conditions and still be readily accessible by air and road. Winter temperatures at Fort Greely have dropped as low as 63° F below zero. By way of contrast, summer temperatures have reached a high of 90° F above zero.

The contract for the design of APPR-1a was awarded to Alco Products, Inc. Award of the construction contract to Peter Kiewit Sons' Co., of Seattle, Wash., is unique in the nuclear field in that this is the first time a contracting agency has awarded a contract for a nuclear plant to be built directly from Government plans and specifications. In the past, nuclear plants have been built in "package deals" with the firm that handled design of the plant also acting as prime contractor (as Alco did on the APPR-1). It is also unique in that, in the past, equipment manufacturers have held the prime contracts for design and construction.

Ground was broken at Fort Greely on June 4 and construction was 31% completed as of October 24. Major work accomplished to date includes the erection of the turbine building; fabrication, testing and erection of the lower hemisphere of the containment vessel; and installation of connections to the Fort Greely utility-distribution system. It is anticipated that major equipment will be delivered during the spring and early summer of 1959. APPR-1a is expected to go critical in 1960.

Comparative data for the Fort Belvoir and Fort Greely plants are given as follows:

		APPR-1	APPR-1a
Location		Ft. Belvoir, Va.	Ft. Greely, Alaska
Output	—thermal	10,000 kw	20,000 kw
	—electrical	1,855 kw (net)	1,640 kw (net)
	—heat	—	38,275,200 Btu/hr
Costs	—R & D	$2,000,000	$100,000
	—design	$358,500	$371,642
	—construction	$3,458,360	$4,737,217*
	—fuel elements	$110,701	$160,000
	—test operation	$350,000	—*
	—total	$6,277,561	$5,368,859

*Lump-sum contract includes 4 months of test operations.

The construction costs shown include those of the containment of the reactor and primary system within a vapor-tight, reinforced-concrete structure as an added safety feature required by AEC for power reactors located in highly populated areas. The vapor container for each plant accounts for 10–15% of the total construction costs. For plants in remote areas, this item may not be necessary. (ALPR does not have one.)

Gas-Cooled Projects

OF THE REACTOR CONCEPTS advanced to date, the high-temperature direct-cycle gas-cooled reactor seems to have the best chance of ultimately satisfying the military need for a truly portable power source.

The two major engineering problems in developing such a system concern the reliability of the fuel elements and the gas turbine. The Army and AEC have two facilities under construction to investigate each of these areas. Now being built at the National Reactor Testing Station is the Gas-Cooled Reactor Experiment (GCRE),* which will test experimental reactor cores. The closed-cycle Gas-Turbine Test Facility (GTTF)* now being erected at the Army Engineer Research and Development Laboratories at Fort Belvoir will proof-test gas-turbine-compressor sets and closed-cycle-component serviceability.

Information from the operating program for these facilities should permit, in early 1960, entry into the next development phase, that of operating the first experimental nuclear-powered, gas-turbine electric generating system. Although some of the engineering parameters and detailed planning associated with the program are classified, enough has been released to give a good idea of the scope and direction of the effort.

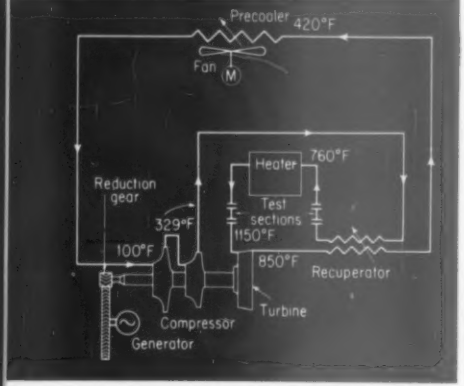


FIG. 1. Flow diagram for turbine-test facility at Ft. Belvoir

Reactor Experiment

The GCRE is essentially a large high-temperature (>1,000° F) gas loop that can be used to evaluate fuel-element performance and corrosion of structural materials. The reactor core configuration consists of a bundle of 73 aluminum pressure tubes located in a tank of water, which serves as moderator and reflector (see figure on opposite page). During operation the core will be critical but will operate at low power to start with; a gas-fired heater will heat the reactor-inlet gas to the desired temperature. The gas exiting from the core will dump its heat to a cooling tower. Thus GCRE for the present at least will not include a turbogenerator.

The coolant gas will be nitrogen. Among the reasons for choosing nitrogen is the hope that field units will eventually operate on air. Minimum materials and component development will then be needed to convert to an air-cooled design. Also, relative to other gases, nitrogen will transit from laminar to turbulent flow at a low flow rate, which permits stable operation over a wide range of partial loading. This is a valuable feature both for a field unit and for the experimental reactor. In addition, cost and assured availability of nitrogen were influencing factors.

Experiments at Battelle have shown that nitriding of materials in contact with the nitrogen coolant can apparently be inhibited by putting small amounts of additives in the gas stream. This will be confirmed with the operation of GCRE and with in-pile loops elsewhere.

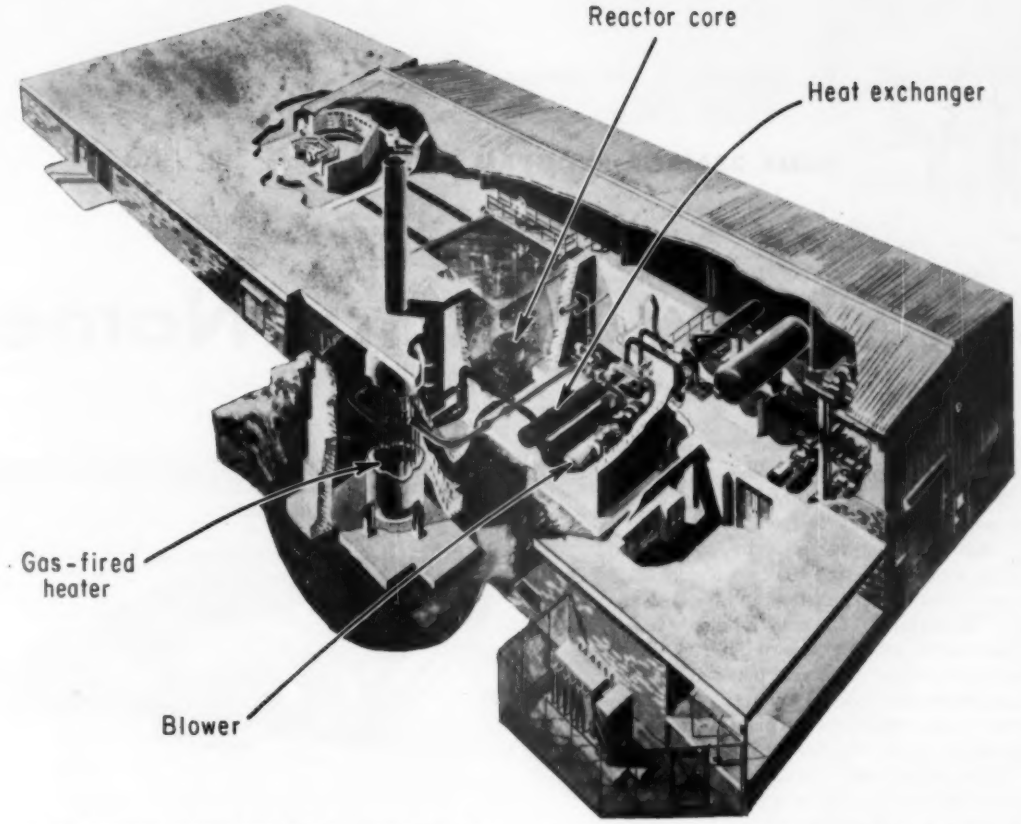
The water moderator and reflector were adopted for reasons of expediency. Ideally, field units should be independent of a water supply. The use of solid materials for these components in later designs is under investigation.

Instrumentation will be provided to collect data on heat transfer, thermal stress, structural stability, pressure drops, temperature gradients, the relationship of degree-hours to burnup, hot-spot temperatures and fission-product activity.

Turbine Test

The other half of the job of developing a portable direct-cycle gas-cooled reactor will begin soon in a specially designed* turbine test facility at Ft. Belvoir. The facility will be used primarily to develop a suitable lightweight gas-turbine-generator set. The specifications call for a unit that will produce 400 kw of 60-cycle 3-phase power with a thermal efficiency of at least 16%. The flow diagram (see Fig. 1) indicates that the nitrogen coolant is heated by an oil-fired heater to a turbine-inlet temperature of 1,150° F. The turbine inlet and outlet pressures are 212 psia and 85 psia respectively. Wherever possible the components used in the test loop will be those designed for service in the "ultimate" power plant. The two test sections will be used to expose materials to nitrogen at the temperatures and

* Aerojet-General Nucleonics has prime responsibility for the design and operation of GCRE. GTTF was designed by Sanderson & Porter and will be operated by Aerojet-General Nucleonics.



GAS COOLED REACTOR EXPERIMENT as it will look when completed. Core, shown submerged in the reactor pool, is roughly 2 ft in diam and 2.5 ft long. Gas-cooled fuel-element assemblies will be suspended in vertical aluminum pressure tubes 36.5 in. long and 1.875 in. o.d. The tubes will be thermally insulated on the inside against the high temperature (~1,000° F) nitrogen coolant. The gas flow rate will be 66,000 lb/hr. Fuel will be highly enriched UO_2 with metallic cladding. Various fuel assemblies are being considered including a nested-concentric-tube design. There will be an intermediate heat-exchange loop in the system to reduce radioactive-contamination hazards and mineral-scale fouling of the primary exchanger.

Reactor will be controlled by moving radial control rods between the pressure tubes. Control-rod worth will be sufficient to maintain shutdown during fuel reloading, at which time the core will be flooded. A set-back rod drives the reactor slightly subcritical if operating parameters deviate slightly from desired values during experiments planned for the first core loading. This should not only minimize thermal shock from repeated scrams but should also be a valuable time-saving device, since the reactor is for experimental purposes and there will be no "ordinary" operations.

pressures of the cycle for corrosion tests.

The preliminary turbomachinery design is a two-stage centrifugal compressor and a two-stage axial-flow turbine mounted on a common shaft. Oil-lubricated journal bearings are located ahead of the first-stage compressor wheel and between the second-stage wheel and turbine. This results in an overhung turbine design, simplifying the seal system and structure. The compressor-turbine shaft assembly is assembled with the compressor diaphragms and turbine inlet scroll and inserted in a barrel-type housing. While this type of structure does not allow easy maintenance it has the advantage of eliminating the horizontal joint, normally a source of leakage.

The only open-end shaft in the turbomachinery is at the compressor inlet end. A gas-tight seal is required at this point to prevent leakage of working fluid from the power plant.

The compressor-turbine shaft system might be developed to run on gas-lubricated bearings, as has been done on lightly loaded high-speed machinery. While the bearing requirements of the compressor-turbine set are beyond anything presently being done, the advantages make an investigation of their use worth while. Briefly, such a system makes possible the elimination of oil seals and drains, resulting in a considerable simplification of the mechanical design. A development program on this bearing type has been started at the Franklin Institute Laboratories for Research and Development. This program is to establish the feasibility of the design and whether the bearings should be hydrostatic or hydrodynamic, i.e. whether they will establish their own film pressure or require pressure supplied from an external source.

ARMY REACTOR PROGRAM

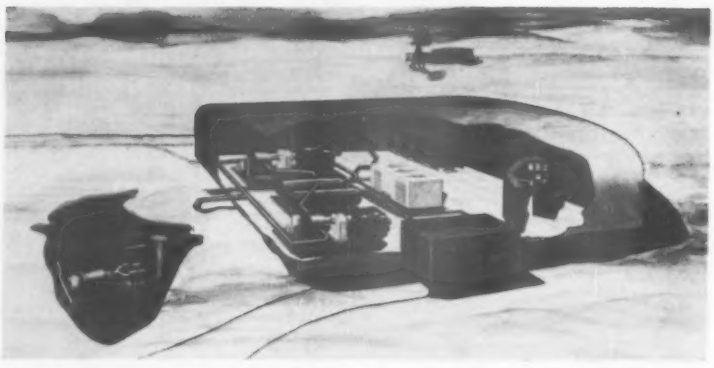
New Reactor Names

Faced with a growing roster of alphabetical reactor names, the Army Nuclear Power Program has decided to simplify things by adopting an automatic system of designation that depends on reactor characteristics and senority. Henceforth each ANNP power plant will be officially known by two capital letters and a numeral plus an optional additional letter as follows:

- The first capital letter refers to plant mobility which will be classified as **S**, **P** or **M**. **S** stands for stationary and refers to a stationary operating plant that is not designed for subsequent relocation. **P** is for portable and describes a plant that operates while stationary but, is capable of being dismantled and reassembled at other locations. **M** means mobile and includes plants that can be moved intact or virtually intact for use at successive locations or while in movement.
- The second capital letter describes the design power for continuous operation:

Symbol	*Power Range [kw(e)]*
V = very low	<100
L = Low	100–1,000
M = medium	1,000–10,000
H = high	>10,000

- The third character is a numeral that specifies the order in which plant concepts of the same mobility and power range were developed.
- Finally, the field plants of each reactor type will be distinguished from the original prototype by adding a capital letter to the basic three-character designation. If more than one prototype or pilot plant is built the succeeding ones will be distinguished by adding lower case letters.



PM-1, new Air Force modular reactor for use at remote locations is shown in artist's version

With these rules in mind it is easy to see that SM-1, SM-1A and SL-1 are really APPR-1, APPR-1a and ALPR. Actually ANNP does not plan to suppress the old familiar names for these three systems. Starting with PM-1, however, (see figure) it will insist that all new reactors be named by the numbers.

PM-1, the first reactor to be christened under ANNP's new naming system, will be a pressurized-water modular-type reactor for the Air Force. The new concept will have a 1 Mw(e) output which makes it larger than ALPR but smaller than APPR. The plant will use factory-assembled modules that can be air-transported and rapidly connected at the site; the plant can later be assembled and relocated if desired.

Construction of the prototype plant will begin this year and will take 30 months. The complete plant will be installed and test operated at Sundance, Wyoming, a new Air Defense Command Aircraft Control and Warning site. Besides the electrical output the plant will also supply Sundance with 2 Mw of heat. Nine bids have been received from manufacturers for the prototype plant (NU, Jan. '59, 25).

REPRINTS

REPRINTS of this special report on the Army Reactor Program, including the foldout description of the Argonne Low Power Reactor on the facing page, are available for 50 cents each. Reprints of the foldout alone are available for 25 cents. Reprint Dept., NUCLEONICS, 330 W. 42nd St., New York 36, N. Y.

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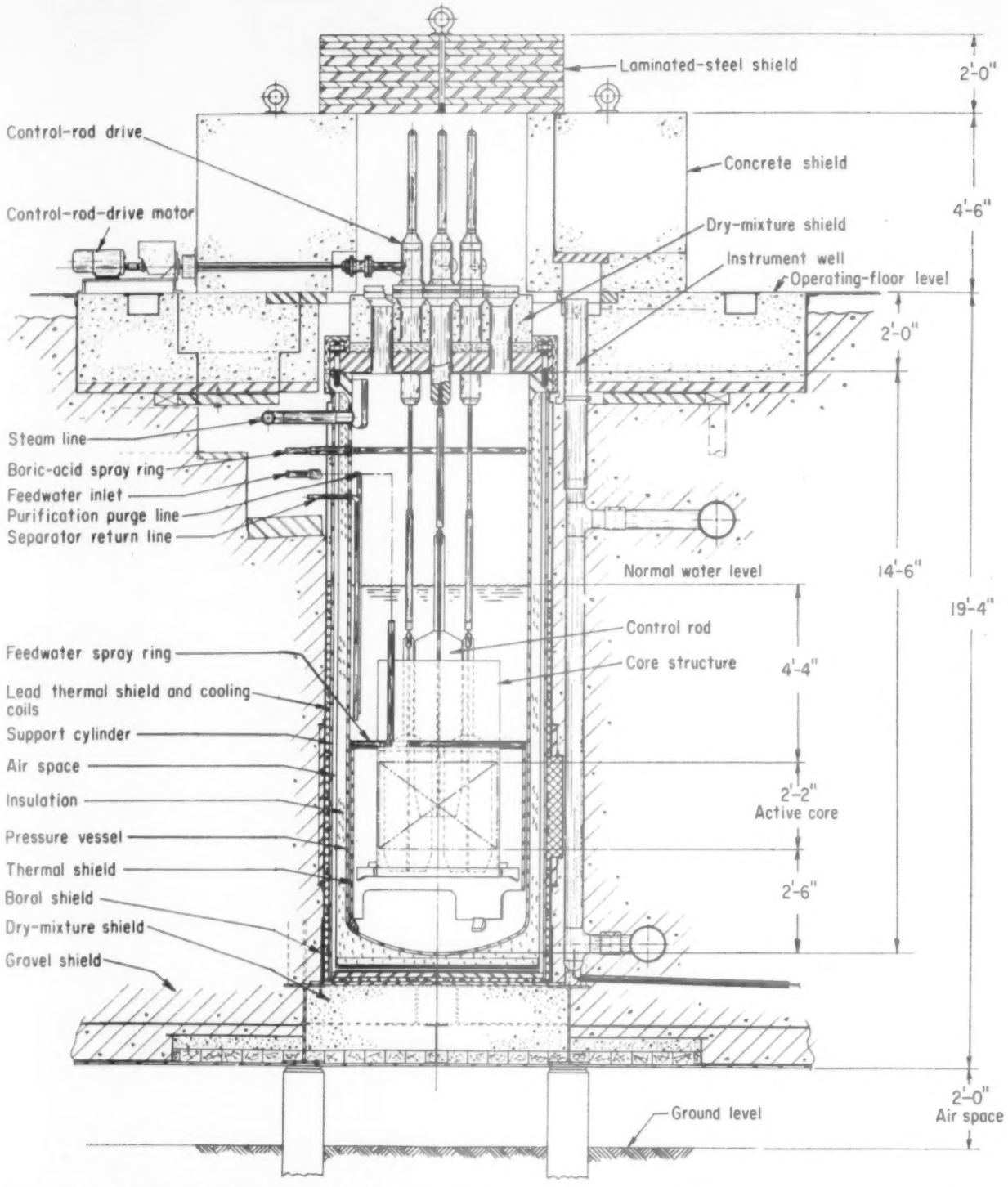
This foldout is removable



1 Reactor. Pressure vessel has welded ellipsoidal lower head and bolted flat upper head. Refueling is done through control-rod-drive penetrations. Coolant flows up core channels and down outside of core where it mixes with, and is slightly subcooled by, feedwater entering through spray ring. About ¼ of reactor heat is required to raise coolant to saturation. Changes in uses of lines penetrating pressure vessel since drawing was made include injection of boric acid through lower feedwater spray ring instead of (as shown) through upper feedwater spray ring. In addition, steam separator has been eliminated from primary-coolant system and its return line will be used only for experiments

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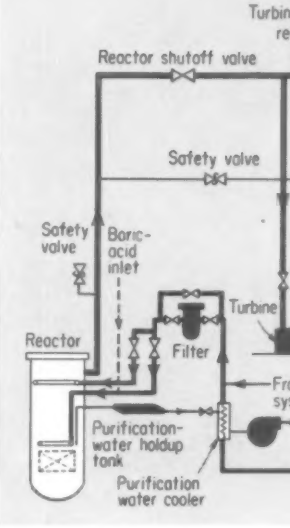
ALPR o

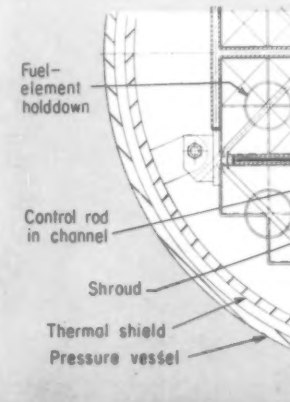
ALPR went critical on Augus
There followed a series of critica
the fuel and burnable-poison loa
3 yr of operation at 70% load
elements and five control rods.
full 59-element core that woul
worths of banks of five and nine
into the core. Using heat supp
hot 40- and 59-element cores by

On October 24, ALPR achi
During October 29–30, a 40-hr
8 hr later, the reactor was brou



2 ALPR flow diagram. Plan
air cooling, feedwater, wa
Normally, ~85% of steam

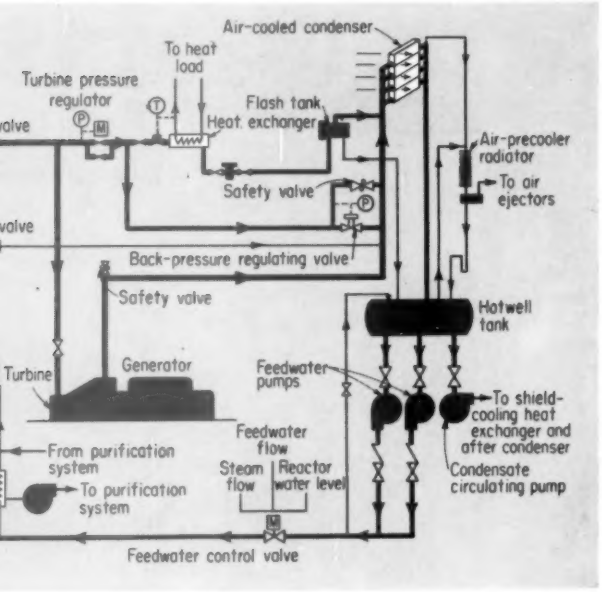
3 Core. With space for 60 fu
put with 40 elements and 5
plate; center 16 have half o



on the Line

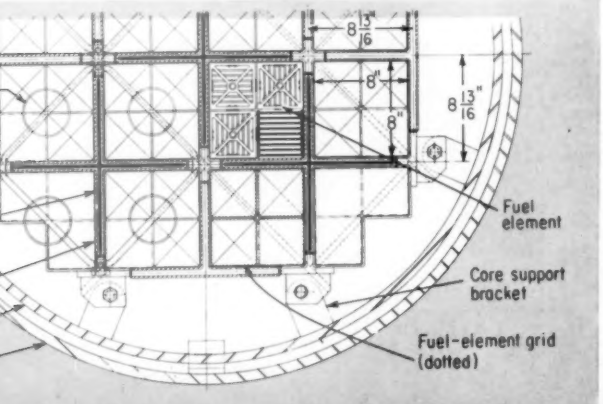
August 11, 1958 with ten fuel elements containing 3.5 kg of U^{235}. f critical experiments, performed in the reactor itself, to determine ison loading necessary to insure 3-Mw(th) capability at the end of % load factor. Those design objectives were met by using 40 fuel l rods. However, critical experiments were also performed on a at would have higher capability. The differential and integral nd nine control rods were obtained as a function of rod penetration at supplied by a portable, gas-fired boiler, flux plots were made of ores by irradiating gold and copper wires, respectively.

R achieved its full-power output of electricity and space heat. a 40-hr xenon run was made. ALPR was then shut down and, as brought to full power, overriding peak xenon.



. Plant has systems for steam bypass, space heating, condenser ter, water purification, shield cooling and boric-acid injection. of steam goes to turbine, ~15% to heat exchanger

for 60 fuel elements and 9 control rods, ALPR achieves rated out- ts and 5 rods. Each element has 26-mil poison strip on one side e half of 21-mil strip on other plate. Metal-to-water ratio is 0.5



Characteristics of ALPR

Location:	National Reactor Testing Station, Idaho
Designer:	Argonne National Laboratory
Owner:	U. S. Atomic Energy Commission
Estimated cost—R&D:	$606,000
—reactor plant:	$1,130,000
—turbine plant:	$856,000
—total:	$2,592,000
On line:	October 24, 1958
Output—thermal:	3,000 kw
—electrical:	300 kw
—heat:	400 kw

Component Design Data

Pressure vessel

Inside height:	14½ ft
Inside diameter:	4.34 ft
Wall thickness:	0.75 in.
Composition:	carbon steel (SA-212)
Cladding	
—material:	stainless steel (304)
—thickness:	0.188 in.
Design pressure:	400 psig
Test pressure:	600 psig

Core

Configuration:	right cylinder
Size:	31.5 in. dia × 25.8 in.
Fuel load:	14.0 kg U^{235}
Burnable poison:	23 gm B^{10}
Composition	
—H_2O:	33 vol%
—Al-Ni-U:	8 vol%
—Al-Ni:	59 vol%

Control rods

Configuration:	cruciform
Number	
—shim:	4
—regulating:	1
Composition	
—poison:	Cd
—cladding:	Al-Ni
Total rod worth:	17% $\Delta k/k$
Weight:	49 lb
Withdrawal rate	
—shim:	3 in./min
—regulating:	1.8 in./min
Scram time:	<2 sec

Control-rod drives

Type:	rack and pinion
Number:	5
Power requirement:	220 v, 3 ϕ
Motor rating:	0.48 rpm, ⅛ hp
Position-indicator accuracy:	±0.05 in.

Fuel elements

Type:	plate
Number:	40
Enrichment:	91%
Plates per element:	9
Meat dimensions:	0.05 × 3.5 × 25.8 in.
Meat composition	
—Al:	80.5 wt%
—Ni:	2 wt%
—U:	17.5 wt%
Cladding:	Al-Ni
Plate temp.—avg:	440° F
—max:	450° F

Nuclear Design Data

Moderator

Type:	light water
Average neutron energy:	~0.053 ev
Thermal-neutron flux—avg:	7.5×10^{12} n/cm²/sec
—max:	$\sim 2 \times 10^{13}$ n/cm²/sec
Prompt-neutron lifetime:	$4\text{–}8 \times 10^{-5}$ sec
Eff. delayed-neutron fraction:	0.0065
Over-all temp. coefficient:	~1.5%/° F

Control requirement

Burnup:	~3% $\Delta k/k$
Peak xenon:	0.6% $\Delta k/k$
Equilibrium xenon and samarium:	2.6% $\Delta k/k$
Temp. coefficient:	1.5–2% $\Delta k/k$
Voids:	1.3–2% $\Delta k/k$
Total:	9–10% $\Delta k/k$

Heat Transfer Data

Coolant

Type:	light water
Volume—total:	3,800 liters
—in core:	215 liters
Inlet flow:	18 gpm
Inlet temperature:	175° F
Operating pressure:	300 psig
Outlet steam temp.:	420° F
Outlet steam flow:	9,020 lb/hr
Recirculation rate:	130 lb/lb of steam

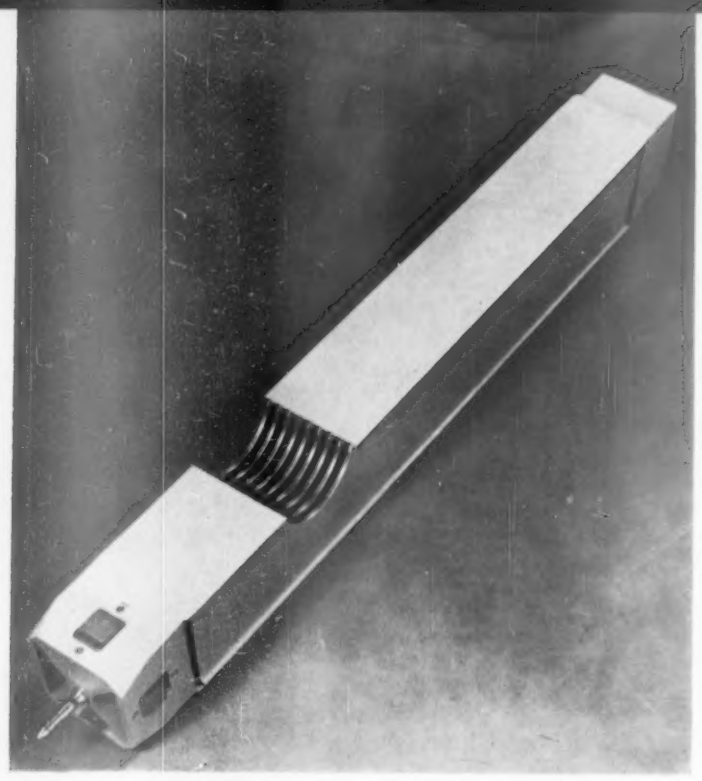
Heat flux

Max/avg ratio	
—axial:	1.3
—radial:	1.6
Core—average:	~22,500 Btu/hr/ft²
—maximum:	~65,000 Btu/hr/ft²

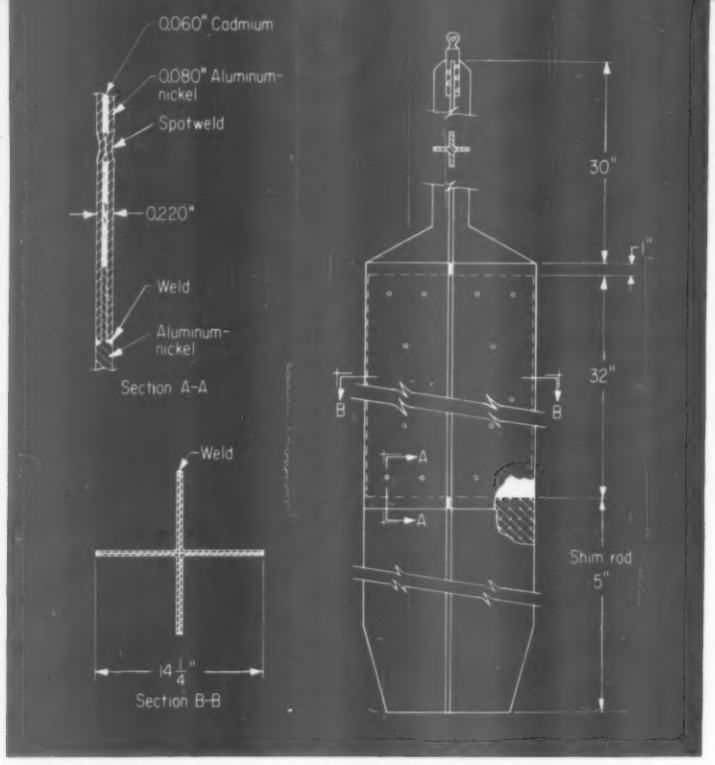
Reactors on the Line

ALPR

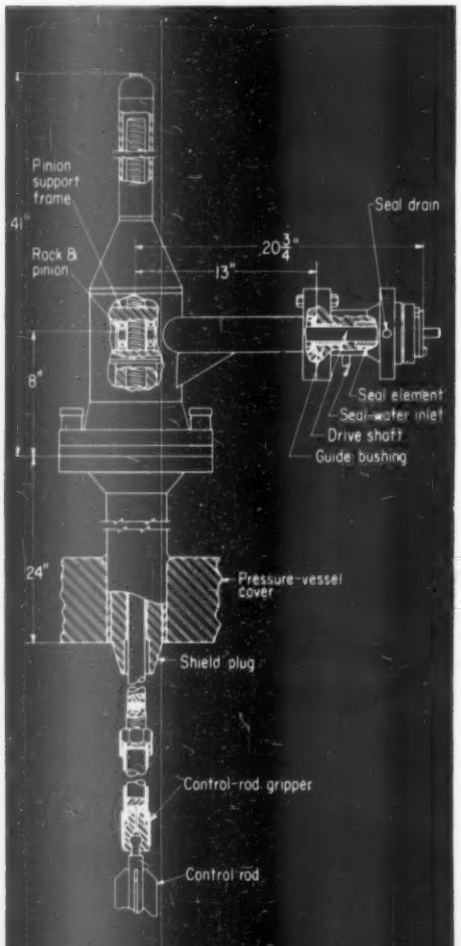
Argonne Low Power Reactor



4 Fuel element. Its plates are 27.8 in. long, 3.710 in. wide and 0.120 in. thick. To usual Al-U meat has been added 2 wt% Ni; special Al-Ni cladding has 1 wt% Ni. This element is cut away to show plates

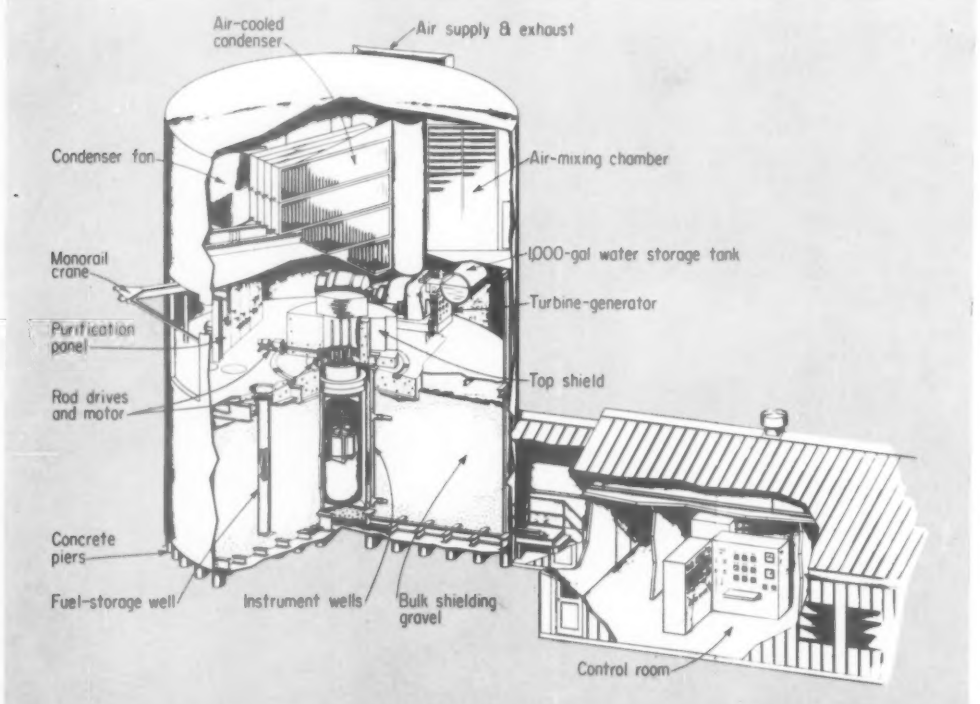


5 Control rod. Cd is held in place by Al-Ni sheets pressed into holes and spot-welded. Absorber section overlaps active core length. Follower section of regulating rods is 19 in. long



6 Control-rod drive mechanism. External thimble has seal through which small amount (~0.1 gpm) of primary coolant is bled continuously to lubricate shaft and prevent accumulation of decomposition gases produced in reactor. In event of power failure, gear motor (not shown) has independent supply

7 Housing for ALPR plant is cylindrical, continuous-welded steel shell 38 ft 7 in. in diameter and 48 ft high secured around structural-steel framework. Bottom of housing rests on concrete piers 2 ft above grade. Air space reduces heat transfer to ground, which, if arctic permafrost, must remain frozen



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escription of ALPR

rgonne Low Power Reactor (ALPR) is a direct-
ling-water reactor moderated and cooled by the
rculation of light water. Pioneer Service & Engi-
Co., Chicago, Ill., was architect-engineer, and the
constructor at National Reactor Testing Station,
as Fegles Construction Co., Minneapolis, Minn.
LPR is the prototype of a packaged power plant
nction will be to power radar equipment and
cent offices and barracks at remote arctic instal-
Among its advantages for this purpose are
ving:
n be transported easily in cargo aircraft; no single
nt weighs more than 10 tons or has dimensions of
n 20 × 7 × 9 ft.
designed to be built on any terrain; no excavation
ry because ALPR is mounted on concrete piers.
inuous supervision during operation may not be
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ill operate continuously for three years with a
l loading.
es not require a large supply of water; the all-
n condenser is air cooled.

Vessel

essure vessel is fabricated from Type SA-212,
Firebox steel. It was designed for 450° F water-
n temperature and 500° F metal temperature.
8-in.-thick cover plate has nine 6-in. nozzles for
d drives and two smaller nozzles for water-level
. Internal base pads support the thermal shield,
turn, supports the core structure. Five con-
through the wall of the vessel are provided for
water inlets, a steam outlet, purification purge
experimental line. The vessel is insulated with 3
gnesia contained in a steel jacket.
essure vessel is suspended by its top flange from
rt cylinder, which, in addition to supporting the
nishes radiation shielding in the form of a blanket
¼ in. thick (with embedded copper cooling coils)
in a ¼-in. steel jacket. At core level, it is
lly shielded by a 1¼-in.-thick steel band.
pport cylinder stands on structural steel at the
the reactor building and is surrounded by gravel
ns the main biological shield. A dry mixture
hot, boric oxide, gravel and sand fills the space
structural steel. Ring-shaped concrete shield-
e operating floor above the reactor is cast in
e sections. A removable masonite-and-steel
shield covers the hole.

ructure

ntire core structure is fabricated of X-8001
-nickel alloy (1 wt% Ni). The core support is a
four interlocking, welded bars, 42 in. in length
ide and ½ in. thick, and extruded cross- and,
vertical stanchions. The sides of the lattice are
by welded support bars. The eight corners of
e are welded to eight blocks (2½ × 3½ × 2 in.)
ne alloy that form the support pads.

The core shroud consists mainly of $5\frac{1}{32}$-in. sheet stock, ~62 in. long and 16 in. wide, formed into large angle sections perforated with equally spaced 2-in. holes. Each pair of angle sections is flush-riveted to the vertical stanchions of the core support to form 16 square boxes (each to contain four fuel elements except for the four corner boxes, which contain three fuel elements each). The sides of these boxes define the five cross- and four T-shaped control-rod channels. Welded inside each box at the bottom are egg-crate-shaped supports to seat the bottom end fittings of the fuel elements.

The core support and shroud rests on and is fastened to an arrangement of eight support brackets welded to the thermal shield. Six brackets have holddown bolts that fit through the support pads of the core support and shroud. The remaining two brackets have special aligning pins that fit through the remaining two support pads.

Fuel Elements

Each fuel element is 34½ in. long by 3⅞ in. square and is composed of a bottom end fitting, nine fuel plates, two side plates and a top end fitting. Each fuel plate is bent lengthwise on both sides to form a flange. After bending, the ends are machined to provide exact spacing for the water channels (0.31 in.) between plates. The nine plates are spotwelded to the side plates.

The top fitting consists of an extruded spider section welded at the inside corners to an extruded rectangular section. The spider section is drilled and tapped to take a stainless-steel handling gripper. To a machined-out piece on each side of the rectangular section is riveted a stainless-steel spring that provides for proper spacing and alignment of the elements.

To reduce control requirements, consideration was given to the uniform dispersal of a burnable poison, B^{10}, in the fuel meat. Because it proved difficult to fabricate well-bonded fuel plates having a fixed amount of B^{10} on schedule, the choice fell to thin strips (21 and 26 mils) of Al-Ni containing 0.42 wt% B^{10}. These strips are 25.8 in. long and 3.875 in. wide and are welded to the side plates of the fuel elements.

Control Rods and Drive Mechanisms

ALPR's cruciform control rods are made of cadmium with aluminum-nickel-alloy cladding and follower sections. The rods are connected to drive mechanisms by stainless-steel, ball-joint end fittings.

Vertical linear motion is imparted to the rod by a rack-and-pinion mechanism mounted above the reactor. The rack and pinion, pinion support bearings and rack backup roller operate in the primary coolant. A labyrinth-type pressure-breakdown seal is used on the shaft. A conventional ⅛-hp electric gear-motor with a magnetic-disc brake is positively engaged to the pinion drive shaft by an electromagnetic clutch. A unidirectional cam clutch will drive the rod down in the event of a scram if the magnetic clutch fails. A synchro-transmitter is coupled through gears to the pinion-drive-shaft extension for positive indication of rod position.

Primary Coolant System

Feedwater enters the reactor through a spray ring just above the core and flows down the annulus around the core, where it mixes with the down-coming coolant to make it slightly subcooled. This phenomenon, plus the lower density of the water-steam mixture in the channels within the core, causes natural circulation of the mixture upward through the core. For every pound of steam produced, roughly 130 lb of water are circulated through the reactor.

About 85% of the steam produced in the reactor enters the turbine at 275 psi and is exhausted to the air-cooled condenser at 4.85 in. Hg. Air is circulated over the finned condenser tubes by a 90-in., fluid-drive, 75-hp fan delivering ~93,000 cfm. About 15% of the steam produced enters the heat exchanger to produce space heat. All returned feedwater is filtered. Reactor water is continually pumped (5 gpm) through a purification system to maintain total solid concentration of <2 ppm.

In addition to the conventional, automatic turbine controls, three major automatic control systems are associated with the process system.

Reactor-pressure control. Steam can be bypassed to the condenser through two valves connected in parallel; they are controlled as a function of reactor steam pressure so that total bypass steam flow is proportional to pressure deviation from a set point. Two valves are required because of the wide range of bypass flow. The valve drive and controllers are so coordinated that the flow-*vs*-pressure characteristic is approximately linear.

Condenser-air control. To keep the air-cooled condenser from freezing when outside temperature is low (design minimum air temperature is −60° F), the temperature of condenser inlet air is regulated by recirculating a variable fraction of the total air flow through a mixing chamber. To implement this system, the average temperature detected by 12 thermocouples distributed across the inlet face of the condenser is fed to a temperature controller. This, in turn, controls damper drive motors on both the air-exhaust duct and mixing chamber. Both the ratio of travel and the bias of the two damper drives can be adjusted.

When maximum condenser capacity is not required, condenser-fan speed is reduced. For this purpose a second group of 12 thermocouples senses the average temperature on the condenser outlet face. A second temperature controller utilizes the signal to regulate fan speed through control of a variable hydraulic coupling.

Feedwater control. The reactor operator has the option of selecting a three-element control based on reactor-water level, total steam flow and feedwater flow, or a single-element control based on reactor-water level alone. Water level is held constant in the pressure vessel by the integrating three-element control system to insure steady operation and complete immersion of the core. This system regulates the feedwater flow to the reactor automatically by: (a) simultaneously measuring the water level, steam flow and feedwater flow; (b) integrating the electrical signals from the measurements; and (c) electrically adjusting the feedwater flow valve.

* * *

For more detailed information, see A. Smaardyk, ed., Hazard summary report on the Argonne Low Power Reactor (ALPR), ANL-5744 (1957).

On December 16, 1958 the Pennsylvania Power & Light Company and Westinghouse Electric Corporation announced the suspension of the Pennsylvania Advanced Reactor Project (PAR) because construction of a large-scale aqueous homogeneous plant was technically infeasible at that time. It was recommended that prototype plant development and operating experience should be part of further development of the PAR reactor type. A brief resume of the accomplishments of the project and the reasons which led to its suspension are set forth below.

The PAR project was initiated in 1955 as a research and development program entirely supported by private funds. The program was to determine the feasibility of a full-scale homogeneous plant in the 150 Mw(e) size range, with an 80% plant availability factor. The initial expectation was that 2½ years of research, plus the knowledge to be gained through the homogeneous development work then under way at Oak Ridge, would produce enough information by the end of 1957 to determine feasibility and to provide a basis for a prudent decision on the building of a large scale plant.

However, by the end of 1957 sufficient data had not been obtained to make a decision on plant construction, despite project expenditures of $5.5 million. It was therefore felt necessary to extend the program. The Atomic Energy Commission was asked to provide $7-million for future research and development during 1958–59, with final disposition to depend on the outcome of the two-year development program and the decision about building a large scale plant. This arrangement was subsequently accepted by the Commission and approved by the Joint Congressional Committee on Atomic Energy. A central feature of this project was that it should be possible to determine technical feasibility in time to permit completion and initial operation of the full-scale plant by the end of 1963. The arrangement expressly provided that either the Commission or the companies could terminate the project for any reason prior to the end of the two-year period.

However, contractual negotiations with the Commission had not been completed as of the suspension date, so all expenditures in 1958 were paid by Westinghouse and PP&L (with Baltimore Gas and Electric Company participating) making their aggregate cost for the project to date approximately $9 million, about 40% of which was for materials and equipment specifically designed for the project. The major part of the remaining cost was for payroll; there were 115 persons directly engaged in the project at the time of suspension, of whom 70 were engineers and scientists.

Why the PAR Homogeneous Project Was Suspended

By W. E. JOHNSON, Manager
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and S. C. TOWNSEND, Manager
Atomic Engineering Dept., Pennsylvania Power and Light Co., Allentown, Pa.

THE PENNSYLVANIA ADVANCED REACTOR (PAR) project, started in 1955 by the Pennsylvania Power and Light Co., and Westinghouse Electric Corp., was directed at the building of a single-region aqueous homogenous reactor. During the three and a half years the project was active, important progress was made toward the solution of many of the problems faced in the construction and operation of this type of plant and of fluid-fuel reactors in general. Much of this has been described elsewhere (*1–4*). What follows are highlights of developments that influenced the decision to suspend work on the project.

At the inception of the PAR program, the existing work then underway at the Oak Ridge National Laboratory was evaluated. With the success attained by the HRE-1 and the construction program then underway for HRT (a two-region machine with a solution core and a slurry blanket), it was considered that successful operation of HRT, in combination with PAR research and development, could reasonably be expected to produce information that would allow scaling up to a full-sized plant.

As time has passed, the feasibility of going directly to the full-scale plant has decreased. The HRT program did not progress at the rate initially planned and the slurry blanket was never operated. At the same time, while no single problem facing the PAR slurry reactor appeared unsolvable, there remained many problems for which complete solutions had not been worked out. This multiplicity of uncertainties in important areas of research, made increasingly critical in view of project time limitations, made doubtful the achievement of the contemplated 80% availability factor. This led to the conclusion that the construction at this time of a large-scale homogeneous plant of the PAR type was not technically feasible.

The reactor cycle that was the focus of the PAR experimental and design studies is shown schematically in Fig. 1. It is an aqueous homogeneous system based on the thorium-uranium cycle. The primary system generates 550 Mw(th) in a 12¼-ft-o.d. single-region spherical vessel, through which flows a suspension of oxides of thorium and uranium in heavy water. The flow rate is 32,000 gpm; inlet and

outlet temperatures are 465° F and 580° F, respectively; and, primary system pressure is 2,000 psi. Upon leaving the reactor vessel the flow divides into four 16-in. loops, shown as one in Fig. 1, and gives up its heat in four 10,000-ft²-steam generators, one in each loop. Steam is generated on the secondary side at 400 psia; electrical output is 150 Mw. The proposed plant comprises, in addition: a gas-handling system, a fuel-handling system, an integrated on-site chemical processing system, and a hot shop for the remote maintenance and repair of components.

Based on present-day costs of fissionable material and heavy water, a plant such as this attains maximum fuel-cost economy at a Th concentration of about 300 gm/liter and a U^{235} concentration at startup of about 10 gm/liter. The U^{235} concentration decreases with time and that of U^{233} increases; the net conversion ratio at steady-state is about 0.86. Higher conversion ratios can be attained in such a system by the use of higher concentrations of Th and U and a larger reactor core, but at greater cost. At some future date economies will justify the building of a breeder reactor, but for the near future, the single-region plant is a logical step in the development of a technology that could lead to a two-region breeder reactor.

Because of the reactor's inherent advantages, the decision to drop the project was made only after careful consideration. During 1958 regular quarterly reviews were conducted on the status of the project work and other related developments, and it was as an outgrowth of these reviews that the conclusion was finally arrived at that the project would be suspended.

The seven major problems existing at the end of 1958 along with some indication of the progress made toward their solution are detailed below.

1. Gaseous Recombination

In aqueous slurry fuel reactors, heavy water decomposes radiolytically into deuterium and oxygen and must be recombined for both economic and safety reasons. This can be done either by a catalyst in the reactor system, or by external catalyst beds. In all early designs for PAR, internal recombination was preferred, based on the assumption that if a suitable catalyst was not found, an external system could be used. In these design studies costly and complex auxiliary systems were required to prevent the accumulation of explosive gas mixtures in the external recombiner. As a result, it was concluded that a suitable internal catalyst must be found and thoroughly evaluated before proceeding to a full-scale plant. Some catalyst materials show promise, but uncertainties about the effects of irradiation, corrosion products, and long-term hydrothermal treatment on the properties of these catalysts are great enough to preclude building a full-scale plant.

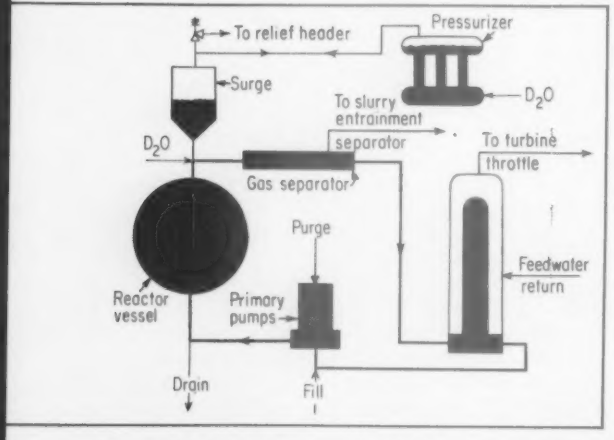

FIG. 1. Simplified flow diagram of PAR primary system

2. Effects of Irradiation on Slurry Properties

Much more information about the irradiation effects on the properties of slurry fuel and on additives (such as the catalyst) was needed before deciding to proceed with construction. To obtain this information, the PAR project entered into a joint program with the Oak Ridge National Laboratory to carry out such work in the new Oak Ridge Research (ORR) Reactor. Fig. 2 shows the first PAR project in-pile slurry test loop, which was to be followed by a series of similar loops. This loop was originally scheduled for operation in the ORR Reactor in March, 1958, but due to technical difficulties and schedule delays, it will not be operated before mid-1959. A program review made it clear that the amount of data available by the end of 1959 from this joint program, even with one or two added test loops, would not be sufficient to recommend full-scale plant construction.

3. Reactor-Vessel Hydraulics

The reactor vessel must be designed to insure uniform distribution of slurry in the vessel and to cool the thermal shields. Progress was made toward the solution of the problem of slurry distribution in the vessel itself. A series of low temperature tests was performed, not only with slurries of thoria but also with low-temperature suspensions of glass beads which simulate the high-temperature settling rates of thoria. The results of these tests were to be verified in a high pressure, four-foot vessel to be installed in loop D (Fig. 3).

Cooling of the thermal shields proved to be a bigger problem than originally anticipated. Several methods have been proposed, but each requires a considerable amount of testing and some would add major complications to the plant system. Only through tests on a prototype reactor can the true magnitude of the problem be determined. For this reason, project engineers and scientists again questioned the feasibility of proceeding directly with full-scale plant construction.

4. Corrosion-Erosion

During the past three years, project engineers and scientists have made considerable progress in determining corrosion-erosion properties materials used to contain or propel the slurry proposed for the full-scale plant. This data was accumulated during some 30,000 hours of circulating slurries through four 200-gpm loops similar to the one in Fig. 3. The data shows that with the velocities attained in most of the system, the corrosion-erosion rate will be less than one mil per year. However, where velocities are high, such as on the impeller surfaces of the primary circulating pumps and at the plugs and seats of valves, erosion is a major problem. Screening tests have shown that for these areas, materials such as Zircaloy and titanium hold considerable promise. Because of special flow condi-

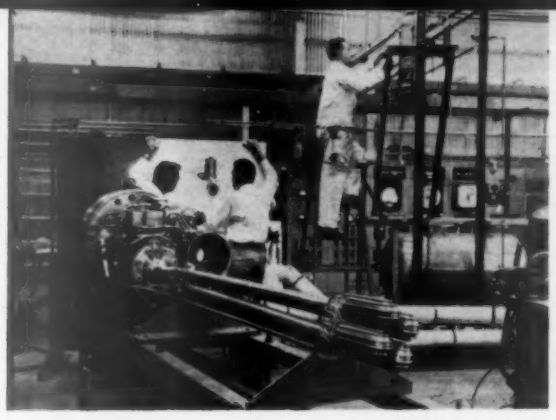

FIG. 2. In-pile slurry loop built for insertion in the Oak Ridge Research Reactor (ORR)

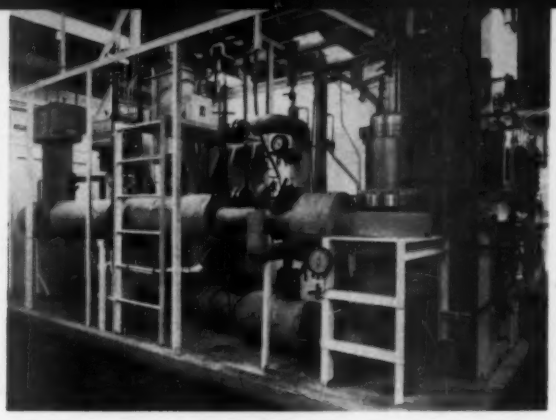

FIG. 3. One of four 200-gpm loops for slurries of thorium oxide and uranium oxide

tions in these high velocity regions, only tests made under actual operating conditions will produce results that can be meaningfully evaluated. For this reason, impellers made of these exotic materials must be tested in loops for long periods of time.

Initial tests on 200-gpm Zircaloy impellers were scheduled to start in early 1959 and tests on 4000-gpm impellers were scheduled for loop D in late 1959. These impellers could have been tested only a few thousand hours by early 1960. The testing of valves of designs similar to those required for the final plant got underway in early 1958. Results have not been encouraging. While test programs on impellers and valves could and would have continued in parallel with plant construction, the amount of pertinent information available by early 1960 would have been extremely limited.

5. Stress Corrosion

The Project has, in the course of operation of the 200-gpm loops, experienced a number of small high pressure leaks that resulted from stress corrosion. In general, these leaks developed when the slurry was permitted to lie stagnant for long periods. Design of later loops eliminated most of these stagnant areas and the thorium oxide preparation was closely controlled to minimize the chlorides present as contaminants. As a result, chloride stress corrosion has not been encountered in the most recent test operations. There exists, however, a distinct possibility that an operating error, or the accumulation of slurry deposits, could initiate such troubles in the plant. Because the presence of decay heat in irradiated slurry could have an effect on the build-up of such deposits, meaningful information should be obtained through the operation of a prototype reactor at power densities comparable to that proposed for the full-scale plant.

6. Reactor Startup

A problem recognized early in the course of the design studies was that of start-up of a slurry reactor, and particularly, startup after an emergency shutdown during which solids were permitted to settle in the primary system. A number of methods were proposed to handle this problem and some seem feasible, and non-nuclear tests of some of these methods were planned. Calculations show that complete safety can be obtained without the use of external reactivity control such as control rods or reflectors; yet the importance of this problem was one of the factors contributing to the decision against building a large-scale plant at this time.

7. Plant Layout and Maintenance

Problems associated with the maintenance of a fluid fuel reactor plant led to the choice of an all-welded plant, one in which equipment requiring maintenance would be removed by remote means and repaired in an associated "hot shop."

The layout of equipment for remote maintenance caused an increase in the physical size of the plant beyond anything previously expected. In most of the problem areas, answers can only be found through operation of a reactor plant having contamination levels similar to those in a full-scale plant. The extent to which contamination is spread throughout the plant when a component is removed from the system can only be found through the operation of a prototype, although successful techniques for handling such matters have been developed in operating plants such as the HRT, but at the expense of considerable down-time. To use a full-scale power generating plant to develop decontamination techniques appears uneconomical and unwarranted. The writers' present outlook for such a project as PAR has obviously undergone considerable change as the research and development work has progressed from 1955 to date. It has been just this research and development which has produced the appraisal of the cumulative difficulties and uncertainties described in this article.

All of the problems that have been discussed are believed to be solvable with adequate time and effort. Certainly measurable savings in time and a greater assurance of reliability can be obtained by first proceeding with the design, construction, and operation of a prototype. Such prototype should be of sufficient size to produce information that could be extrapolated directly to a full-scale plant of 150 Mw(e) or larger. But there remains a basic question to be answered: what development pace should now be set for the homogeneous reactor within an over-all nuclear power development program? Many elements are involved requiring most careful and thoughtful consideration because of the various changes in circumstances since mid-1955. Westinghouse and PP & L interest in the homogeneous reactor will continue; therefore, we consider that the PAR project has only been suspended.

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TABLE I—Safety Indices (Output per Life Lost)*

Activity	*Index ($ 10^6/life)*
Automobile manufacturing	200
Food industry	87
Chemical industry	62
Iron and steel products	60
Petroleum industry	38
Mining, except underground coal	9.5
Underground coal mining	5.2
All industries (my estimate)	50
Scheduled airlines (output at 7¢ per passenger mile)	7.7
Private car travel (output at 3.5¢ per passenger mile)	0.93
Canadian railways, 1953 (passengers, 2.9¢ per passenger mile; freight, 1.5¢ per ton mile)	7.1
Canadian electricity industry, 1954 (at 5 mills/kwh)	9.0

* Sources: Refs. *2*, *3*, and *4*. Output value estimated at $4 per manhour when not otherwise stated. Figures for United States except as noted.

Statistical Analysis of Reactor Safety Standards

Are we holding back our own progress by wasting money on reactor safety that would be better spent in improved design or even medical research? A method is proposed for finding out

By ERNEST SIDDALL, *Atomic Energy of Canada Ltd., Chalk River, Ontario*

THE STUDY OF nuclear-reactor safety is in an unsatisfactory state. Some aspects of the problem have received quite disproportionate study and expenditure. However, it is almost impossible to discover an over-all philosophy or aim behind this work. This is revealed when important advances in performance of some parts of a reactor are followed by no apparent change of thinking about the whole. The tendency seems to be to demand more assurances and more safety measures as time goes by, despite the extremely favorable record of the industry.

I would like to propose a system whereby risks can be evaluated and efforts to meet them can be properly adjusted in magnitude. My equations are designed to decide how safe a system must be in view of both the cost of making it better and the damage that can result from failure. No doubt there are people who will not be satisfied with this type of approach. If the premises of this paper are right, the attitude of such people verges on simple nihilism, which is not likely to produce much of economic or humanitarian value. If the premises of the paper are wrong, it is urgent that better ones be found.

The basic difficulty in thinking about safety is probably a failure to understand that the intrinsic danger of a process has little or no relationship to the effective danger it actually presents. For example, the annual production of insecticides in the United States exceeds 15×10^9 human fatal doses (*1*). Yet insecticides rank low in accidental deaths by poisoning, and all accidental deaths by poisoning form only a small category. Also, manufacturing photographic film or fertilizers is about twice as dangerous as making explosives or fuses and powder (*2*).

Safety and Dollars

I suggest a common statistical basis to which estimates of both probable consequences of accidents and factors in the design of reactors can be referred. In terms of it design can be seen as an optimization rather than an endless struggle for more safety.

The most useful common basis for most industrial compromises and optimizations is money. In safety studies, however, such a basis involves setting a prior value on human life and to a smaller extent on human suffering. Perhaps the emotional opposition to such an equation raises the greatest impediment to clear thinking and discussion. Besides an economic study, therefore, I attempt to derive a humanitarian balance. By chance, or perhaps for underlying reasons that are not obvious, it appears that the economic criterion is somewhat more severe than the humanitarian one.

Humanitarian Aspect

The worst possible misfortune that can befall a person is death, and, unhappily, all people are at all times exposed to a risk of death. This risk can

be expressed quantitatively as the probability of a person dying in a unit of time. For all Canada in 1954, the lowest mean risk, 0.55×10^{-3} per year, occurred in age group 10–14 (*3*). By comparison, injury less than fatal (say within a month) can probably be ignored, since most nonfatal injuries are followed by fairly complete recovery. Even if there is disability, this can be offset financially, which is not possible with death.

Almost invariably deaths are highly random in time and place since any systematic factor is almost certain to be eradicated very quickly. Thus if we wish to measure the risk that a particular activity represents to a community, the correct unit is the probable number of deaths per unit time it will cause. If it is an established activity, this is the same as the number of deaths per unit time that it actually causes—if one bears in mind that this number is only statistically constant.

It seems self-evident that in this context the actual manner of death, the time and place of death and whether deaths occur singly or in large numbers in particular accidents or epidemics are unimportant. However, corrections may have to be made if mortality is age-selective in a way differing from other risks or if the life expectancy of survivors is reduced as it probably is in almost any type of serious injury.

We have now defined the risk to a community. It seems satisfactory to regard safety as a parameter specific to a type of activity or to a person. In the latter case, a person's safety can be defined as the inverse of his individual risk, and the safety of a community is the average safety of its members. Thus community safety is the number of people in the community divided by the probable number of deaths in the community in unit time.

Safety and Other Goals

However, increasing safety is not the only aim of a community. One of the most dangerous large scale activities in many countries is private motoring. The death rate in road accidents in the United States in 1955 was 0.245×10^{-3} per year. This is equivalent to an average risk of death of about 3.8×10^{-8} per person-mile in private motoring (*4*). Most private motoring is voluntary. Accidents occur quite frequently in most areas, and there is no shortage of publicity. Thus it is clear that on the average this risk is accepted as part of the price of the pleasure and convenience of motoring.

In general, a large fraction of accidental deaths—and at least some so-called natural deaths—could be avoided if more money were spent on safety measures or if wealth were sacrificed by working more carefully and more slowly or in not carrying out some of the more dangerous operations. The actual level of risk in various human activities and industries therefore represents an acceptance level: the product justifies the risk.

If we wish to deduce a universally applicable standard, it must be a ratio between such things as pleasure and wealth on the one hand and risk on the other. Fortunately in most western countries freedom of exchange of money means that such things as pleasure and wealth, at least in the framework of a study like this, can be equated with money. Thus the standard becomes "monetary value of output per life lost."

Table 1 attempts to show this standard for some of the major activities and industries in the United States and Canada in 1955. The value of output is based on the total man-hours worked in each industry since this is the only readily available information that relates the accident record to a scale of operation. The low figures for coal and other mining are actually optimistic. Additional deaths from occupational diseases, notably lung diseases, are not counted as accidental deaths, particularly since many of the victims are not actually employed in the industry when they die.

Mortality Reduction

Another point of great importance is illustrated by Table 2, which shows the decline in general mortality in Canada between 1921 and 1951. The reduction of mortality, particularly in early life, represents a saving of ~340,000 lives in the period shown. Now my guess is that the gross national product (GNP) of Canada for this period is about 3.1×10^{11} 1957 dollars. Roughly speaking, therefore, one life has been saved per $910,000 of GNP. The reduction in mortality can be put down to our general increase in wealth, which has permitted better housing, feeding and hygiene.

Alternatively, it can be argued that

The Author Brings the Problem into Focus

A COMMENT BY W. B. LEWIS

Those engaged in nuclear-power development find themselves facing a problem that can be stated very simply. Nuclear power promises to raise world standards of living, but its development is expensive. The benefits to come will be delayed by the expense not just in simple proportion but by a threshold of cost. A small addition to the expense near this threshold can hold down the standards of living.

In a few decades the world will judge whether we are then more subject to death and poorer than we might have been through overcaution or through underestimate of risk in nuclear power development. The problem is to determine in advance the optimum balance between caution and risk.

Nuclear Progress Is Essential

The atomic energy industry in the free world is known to enjoy a remarkable record of freedom from serious accident; this affords a prized base for confidence that must not be hazarded. On the other hand a maxim such as "Safety at all costs" is valueless, for life in this world is not safe and our current high expectation of life in civilized countries depends on the high standards of living. To extend this to others demands progress in which nuclear power appears essential. Nuclear engineers are therefore obliged to seek a measure for the risks involved in their designs. The author does much to bring this problem into focus; it will not be the last word nor the only viewpoint on this complex subject, but it can be recommended as a significant contribution that sets a high safety standard.

—W. B. LEWIS
Atomic Energy of Canada Ltd.

TABLE 2 Canada "Life Tables," 1921–1951

Age Group	1921 (Excluding Quebec) Population (10^3)	Deaths (10^3)	Rate (per 10^3)	1931 Population (10^3)	Deaths (10^3)	Rate (per 10^3)	1941 Population (10^3)	Deaths (10^3)	Rate (per 10^3)	1951 Population (10^3)	Deaths (10^3)	Rate (per 10^3)
0–4	773	19.1	24.7	1,074	25.7	23.9	1,052	18.7	17.8	1,723	17.1	9.93
20–24	520	1.993	3.84	911	2.955	3.24	1,032	2.371	2.30	1,089	1.543	1.42
40–44	385	2.327	6.05	646	3.381	5.24	676	3.208	4.75	869	3.010	3.47
60–64	167	3.773	22.6	295	6.438	21.8	407	8.771	21.5	506	10.350	20.5
80–84	28	3.632	129.7	49	6.421	131.0	72	9.926	138	97	12.350	127

only a small part of the GNP has in fact contributed to the saving of life in expenditure on medical research and medical services. In either case, however, an increase in GNP is capable of being used to save lives. Thus there is a direct humanitarian reason for increasing our wealth. If a fraction of the GNP is held to have reduced mortality, this cost of saving a life may be very low compared with other safety measures. So the best way to increase our over-all safety is to advance our technology—and thus increase our wealth—as quickly as possible.

Cost of Safety

In the light of the above discussion, we can now see the nature of the humanitarian balance in deciding expenditure on safety measures in the nuclear industry.

On the credit side the nuclear industry will (*a*) reduce the amount of coal mined and transported and thus reduce the number of people killed in those dangerous industries and (*b*) increase the wealth of the community, which we have seen is associated with a saving of life by reduced mortality. On the debit side it will (*c*) cause some deaths and injuries because of the intrinsic danger of the process. If then we add to the cost of reactors and delay the growth of the industry by greater expenditure on safety studies, increased safety margins and more special safety devices, we reduce factors *a* and *b* as well as reducing *c*.

The exact balance point would require knowledge of the differential effects, but where the cost of generated power is about the same as for coal-generated power, as it is likely to be in the early days of the industry, factor *b* is zero and a straight balance between *a* and *c* gives the degree of safety required in the reactor.

Nuclear Power vs Coal

Table 3 is a comparison of the relative contribution to the community risk in nuclear and coal power stations. Of course there are other risks to be considered in the total comparison, but if we make the rather severe assumption that risks of manufacture and construction of the plants are equal, we can find the point at which a nuclear station will break even with a coal station in risk. This will be where the risk arising from accidents peculiar to a nuclear station is greater than that arising from accidents peculiar to coal stations by about $(659 - 75) \times 10^{-12} = 584 \times 10^{-12}$ lives per kwh.

If the power is sold at 6 mills/kwh, this figure corresponds to a safety index in nuclear accidents of $\$6 \times 10^{-3}/584 \times 10^{-12} = \$10.3 \times 10^{6}$ per life lost.

It seems reasonable to take a target five times better than this for the next few years; that is, about $50-million per life lost. Such a risk would be almost negligible in the over-all electrical industry.

Economic Balance

The economic balance is more straightforward. Accidents cost money in (a) loss of revenue from the disabled plant, (b) cost of repairing the plant or writing it off as a loss, (c) cost of compensation to workers and others for injury or damage suffered from the accident. The accident rate can therefore be converted into an average accident cost per year. However, by greater expense this accident cost can be reduced. For example: (a) More money can be spent in research and development work so that the problems are better understood. (b) Greater safety factors can be used in all or some parts of the design. (c) Important components can be multiplied and diversified. (d) Money can be spent on palliatives, such as enclosing shells and exclusion areas.

The accident costs and the costs of measures to avoid accidents can be

Coal Mining May Not Offer a Fair Standard

A COMMENT BY MANSON BENEDICT

I think this attempt to find an appropriate measure of the worth of reactor safety and of the permissible cost of means to improve it is very worthwhile. Siddall's proposition that operation of nuclear power stations can be made safer than mining of coal is an interesting and provocative one. I am not convinced, however, that use of the coal-mining industry as a standard of comparison for the risks that might be allowed the nuclear-power industry is entirely fair. A nuclear-power industry also substitutes for the oil and gas industries. For these the safety indices are much higher than for coal mining.

—MANSON BENEDICT
Department of Nuclear Engineering, MIT
Member, AEC Advisory Committee on Reactor Safeguards

reduced to a common basis, such as equivalent annual charges, by application of the correct interest and repayment rates. The best design is that which gives the lowest total. Expenditure that reduces accidents is more useful than expenditure on palliatives, particularly if the latter make rescue and repair work more difficult. This may be the case with enclosing walls.

Safety Standards

The mechanism of nuclear accidents has received a great deal of study. Unfortunately the usefulness of this has been largely vitiated by disproportionate attention to the "worst possible accident." It is the average accident and its probability that have real meaning.

A good illustration of the difference occurs in the aircraft industry. One could certainly postulate an accident in which 2,000 people were killed if an aircraft crashed on a theatre. Even if no one not in the aircraft is killed, the worst possible accident can still reasonably result in 130 deaths, and this has actually happened. Yet the average number of people killed in 54 scheduled airline accidents in the USA in 1955 was 3.5.

The reason is quite fundamental: The worst possible accident occurs when a number of separate factors, each improbable and to some degree random, simultaneously become as adverse as possible. This is a far less probable condition than that a smaller number of factors are adverse or that there is less adversity or both. This state of affairs makes accidents easier to deal with than they otherwise might be. The more numerous accidents of lower degree provide a warning and produce the right attitude of caution toward larger ones.

The record of nuclear-reactor operation so far strongly supports these assertions. The humanitarian record of the industry in respect to nuclear accidents is far better than any of those shown in Table 1, and the total cost of nuclear accidents has been trivial compared with the whole operation. Nevertheless there have been several accidents causing serious damage to reactors. Clearly, in each of these cases, the combination of adverse factors was far below the worst possible.

Reactor Accidents

The course of events in a serious

The Thesis Is Good; Practice Is Difficult

A COMMENT BY CLIFFORD BECK

The basic thesis in this paper is clearly right, that a struggle for more and more safety in nuclear plants cannot be carried to infinite lengths; that there must somewhere be a point where one is satisfied to accept a balance between the risks involved and other factors. The author is to be commended for the bold approach. It represents a significant contribution to the complex considerations involved in deciding the adequacy of safeguards required in nuclear plants. The enunciation of principles, perspectives and opinions is especially valuable in the provocation and stimulation of thought and imagination, which are particularly needed on this problem.

Ingredients Are Uncertain

The idea that in principle a balance between risk and other factors can be struck and a quantitative measure of adequate safeguards calculated is intuitively attractive. On the other hand, it is difficult to see how the procedures suggested here can in practice lead to quantitatively better decisions than those now arrived at by present, largely subjective judgments.

The basic difficulty arises from the extraordinarily wide range of possible values existing for all the parameters that would go into the equations one would set up in making the calculations outlined. When such essential ingredients of the calculations are so uncertain, it is not possible to obtain a confident answer.

Is it as Good as it Looks?

There are further difficulties with the humanitarian criterion described here. First, the procedure of taking $\frac{1}{5}$ of the difference between the lives lost in the coal preparation process and the lives lost per kilowatt-hour in the nuclear fuel preparation processes as the target or reasonable safety goal for nuclear plant operations would not make the overall nuclear operation a great deal better than the coal operations—which have a particularly bad record. There would be some improvement—but not by a factor of 5 as might at first be assumed. On the other hand, if one should assume that the over-all nuclear process (fuel preparation and operation) should be 5 times better than the record of lives lost per kilowatt-hour in coal preparation alone, the humanitarian criterion would become more severe and would be at least as restrictive as the economic criterion assumed.

There is an even more serious problem with the humanitarian criterion: in the coal processes, bad as they are, the people killed are the workers, who in any industry can be expected to accept the known risks of their employment. In the nuclear industry the tolerated "target" of lives lost would be primarily from the general public. This is one of the vast differences which makes this problem so difficult to deal with. Finally, from nuclear accidents, the humanitarian damages do not stop with those killed. There is not only the problem of the obviously injured but also the delayed-effects aspects of injury to individuals and the possibility of genetic damage—not only to a few individuals but also to significant portions of the population.

Loose and Dubious Procedures

Another criticism arises from the loose and dubious manipulative and calculational procedures used in arriving at the numerical conclusions. This does not necessarily detract from the principles suggested but does make it difficult to follow. This also reinforces the impression of the inherent uncertainties and necessity for subjective judgments in the methods outlined here. It also demonstrates one of the principal reasons it appears impossible to utilize this method practically in defining quantitatively and with confidence a point at which further safety precautions are unnecessary.

The validity of some of the secondary assumptions would be quite debatable when details are examined. For example, it appears reasonable that "intermediate" accidents will be statistically less frequent than "minor" ones, and "major" accidents still less frequent. But to set the ratios thus expected should depend on more than intuition. Moreover how one could always depend on small accidents as warnings in advance of a major one in any particular installation, is at best questionable.

—CLIFFORD K. BECK
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reactor accident seems to be generally agreed. The events after a particular type of release of fission products have been well described (*5*). The report has enough expert information and estimates to permit a reasonable evaluation of the average consequences suitable for the approach outlined in this paper. A similar study (*6*) for a more specific case agrees well enough in its conclusions for our purposes.

However, estimates of the amount of fission products achieving airborne form after a specified type of accident are very dependent on the type of reactor and must necessarily rely more heavily on human judgment. All reactors have one or more integral or superimposed stages of containment of the fuel, and it is the degree of failure of these stages that most affects the degree of the accident. Many reactors have very effective control and protective systems. These can have a radical effect on the probability and intensity of accidents.

A Specific Application

To illustrate what can be done in applying general safety standards to a particular reactor, the case of the Canadian power reactor described in NPG-10 (*7*) can be studied in some detail. This reactor uses natural UO_2 fuel zircaloy sheathed. D_2O at ~520° F maximum temperature and 1,000 psi is the primary coolant. Fuel assemblies will be contained in individual zircaloy pressure tubes, outside which is an insulating gas space and then an unpressurized D_2O moderator contained in a large aluminum tank. The principal shielding is a heavy concrete floor over the whole reactor.

Gross revenue of this reactor at 6 mills/kwh and 0.8 load factor is $8.4-million per year. Therefore the target death rate from nuclear accidents is $\$8.4 \times 10^6/\$50 \times 10^6 = 0.17$ per year, and the break-even death rate with coal generators is about $8.4 \times 10^6/10.3 \times 10^6 = 0.82$ per year.

The economic criterion is more difficult to put into the simple form of a target accident cost, but it appears reasonable to take 2% of the gross revenue. This corresponds to an insurance premium. It seems improbable that further safety measures are justified once the accident cost is reduced to this level. The target accident cost is therefore $168,000 per year.

Let us now consider the basic reactor with those safety precautions that are integral in its present design. We include the highly reliable control and protective systems of NEI-74 and -75 (*8*) and the substantial degree of enclosure afforded by the proposed physical arrangement. We omit any added containing shells and assume a location in the populated area postulated as typical for a large power reactor in Ref. *1*. The exclusion area has a radius of 2,000 ft.

TABLE 3—Power Costs in Lives and Dollars

Operation	*Product*	*Safety category (Table 1)*	*Contribution to electrical-power cost (mills/kwh)*	*Contribution to risk (10^{-12} lives/kwh)*
NUCLEAR				
Mining, milling of U	Precipitate at $9/lb U	Mining, except underground coal	0.49	52
Refining, sintering	UO_2 fuel slugs at $25/lb U	Chemical	0.89	14
Fuel fabrication	Fuel assemblies at $35/lb U	Iron, steel	0.56	9
TOTALS			1.94	75
COAL				
Mining	Coal at pithead, $8/ton	Underground coal mining	2.9	560
Transport	Coal at power station, $10/ton	Rail transport	0.7	99
TOTALS			3.6	659

The worst accident considered is the full-scale nuclear runaway. Temperature coefficients of the reactor are rather low, and if means are provided for restarting after short stoppages or if large changes in output are considered, excess reactivity will be well above that required for prompt criticality at all times. This excess reactivity will be held by the operating control system. A variety of protective devices are part of the protective system, which will prevent all stages of a runaway if it functions correctly. The full-scale runaway therefore requires that (*a*) the operating control system increase reactivity at the maximum possible rate with (*b*) a simultaneous complete failure of the protective system. Other possibilities are conceivable, but these are of such lower probability that they can be ignored by comparison. Let the average frequency of occurrence of *a* be f_{oa} and the probability that condition *b* exist be p_{pf}.

The consequences of the accident are assumed to be the escape to airborne form of 10% of the solid fission products and 50% of the volatile fission products. With additional assumptions one can deduce the deaths and damage caused by given releases (*5*). The figures for this worst accident are 222 killed and $448-million damage. The contribution of this accident is therefore $f_{oa} \times p_{pf} \times 222$ killed, $f_{oa} \times p_{pf} \times \$448$-million damage.

Among less serious accidents are the following:

(*c*) **A nuclear runaway of lower degree.** The operating control system only partly or slowly runs away, or the protective system is only partly disabled. Partial disabling happened, for instance, in the NRX and EBR-1 accidents.

(*d*) **A primary-coolant-system burst and failure of the protective system.** It is reasonable to assume that each of the component probabilities in *c* is ten times as great as in the preceding case, so that the probability of the condition is $100\, f_{oa}p_{pf}$. Let f_{ob} be the probability that the primary system will burst in one year's operation. The total probability of this order of accident per year is $100\, f_{oa}p_{pf} + f_{ob}p_{pf}$.

The airborne release for this type of accident is assumed to be 0.5% of the solid fission products plus 5% of the volatiles. Thus death and damage numbers are: killed, 22; damage, $44-million. The risk contribution is:

killed, $(100\ f_{ou}p_{pf} + f_{cb}p_{pf}) \times 22$ per year; damage, $(100\ f_{ou}p_{pf} + f_{cb}p_{pf}) \times \$44 \times 10^6$ per year.

In addition we will have damage caused by lesser accidents, particularly by bursting of the primary coolant system even when the protective system works correctly. It is assumed that the cost of repairs and loss of revenue is $\$5 \times 10^6$.

Remembering that the target death rate is 0.17 per year and the target accident cost $168,000, we can express the two criteria by the following equations

(Humanitarian)

$$f_{ou} \times p_{pf} \times 222 + (100\ f_{ou}p_{pf} + f_{cb}p_{pf}) \times 22 = 0.17$$
$$(2422\ f_{ou} + 22\ f_{cb})p_{pf} = 0.17$$

(Economic)

$$f_{ou}p_{pf} \times 448 \times 10^6 + (100\ f_{ou}p_{pf} + f_{cb}p_{pf}) \times 44 \times 10^6 + 5\ f_{cb} \times 10^6 = 0.168 \times 10^6$$
$$(4850 f_{ou} + 44 f_{cb}) \times p_{pf} + 5 f_{cb} = 0.168$$

It will be seen that f_{cb} must not exceed $0.168/5 = 0.0336$ per year, and that the values of f_{cb} and f_{ou} will always be limited by the economic criterion.

One reasonable "solution" to these equations is $f_{cb} = 0.02$ per year, $p_{pf} = 0.002$, $f_{ou} = 0.006$ per year.

Now we can translate these figures into targets for individual designers:

The primary coolant system must be designed so as not to burst more often than an average of once in 50 years.

The protective system must not completely fail, despite failures in the operational control system and bursting of the primary coolant system, more often than on one occasion in 500. Partial failures of the whole system can be tolerated on one occasion in 50 at the most.

The operational control system must not fail at full speed in the direction of increased reactivity more often than once in 160 years. Partial "net-upward" failures of the system can be tolerated once in 16 years.

In the light of present knowledge and techniques, these targets seem to be reasonably attainable.

What Does it Mean?

It can be argued that the probable errors in this process are very large. This is true, but this is offset by the warning provided by minor incidents, which are much more probable than major ones. In control systems, in fact, this feature can be exploited so far that statistical experience can be built up on minor mishaps that result in no consequential damage at all. The system, can be much more reliable than its component parts. In bursting of the pressure system, the warning incidents —bursts followed by prompt shutting down of the reactor—carry only an economic penalty that should not be crippling. Needless to say, if the operating record shows that the safety criteria are not being satisfied, the design of the reactor must be changed.

Meeting of performance targets can be checked from experience in time to avoid major accidents. If targets are met, money spent on a containing shell and consequent additions would be wasted. Economically, the reduction in cost of accidents would be less than the annual charges on the shell. From the humanitarian viewpoint, the money would have been better spent on safety measures in a dangerous industry, or better still, on medical research.

* * *

This article is based on the author's report CRNE-726 (Chalk River, 1957). Lewis's comment is taken from the foreword to that report. The other comments were solicited by NUCLEONICS.

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For a Planned Society—And Why Not?

A COMMENT BY GUNNAR RANDERS

This article attempts to bring a sense of comparative values into the safeguards problem. It is of particular relevance to the people who direct reactor projects. Top-level decisions must be made in design and operation that balance the cost of safety against the benefits of safety.

A First Good Step

A certain amount of courage and imagination is required to undertake such vague concepts as the dollar value of human lives, and it is not surprising to find that the author's treatment is oversimplified and weakened by compounded assumptions. Nevertheless this paper signals the first step in introducing safety consideration into the economic optimization of reactor complexes.

The next step might be to enumerate our safety features, what they cost, and what they are worth. This would surely uncover some areas that have been overemphasized and others that have been neglected. We suspect—and an analysis such as this is necessary to confirm it—that the money so commonly lavished on containment shells could have been better invested in the realm of operator training and operational standards. Whether it could also be better used for hospitals brings the whole complex of modern social organization into the picture.

Are Stricter Standards Needed?

It could be argued that operational analysis should then be extended to the whole society with its numerous hazards of daily life. The question might further be raised whether all new achievements giving material benefit to us all should be measured with the standards of safety already used, or if the standards should be stricter since we introduce new hazardous factors.

The operational analysis should thus incorporate old and new hazards and a possible weighting factor. The weighting factor should give place for the uncertainty in the evaluation of future development within each new field of activity.

We are then moving towards a technically and economically planned society—and why not?

—GUNNAR RANDERS
Director, Joint Establishment for Nuclear Energy Research, Lillestrom, Norway

Are Plateaus Significant in Scintillation Counting?

By RALPH W. ENGSTROM and J. L. WEAVER
Radio Corporation of America, Lancaster, Pennsylvania

EDITOR'S NOTE: *After an afternoon session of the January, 1958, Scintillation Counter Symposium in Washington a group remained to discuss plateau characteristics of scintillation counters. The discussion was continued through the mails and benefited from the comments of many experts whose contributions are hereby acknowledged.*

A counting plateau can be defined as a range of counter voltage over which the counting rate is relatively constant. As applied to a gas-filled G-M counter, the counter voltage is the one applied between the center-wire anode and the shell. As applied to scintillation counters, it is the voltage applied to the multiplier phototube.

For both kinds of counters the concept has some usefulness. It enables the user to make a simple, satisfactory adjustment of his instrument. Operation on the plateau provides for a minimum counting-rate change with fluctuation of voltage and changes in component characteristics.

In the G-M counter, length and flatness of plateau are measures of good design and operation. On the other hand, it is not obvious that this is true of scintillation counters. Length and flatness are indeed related to such desirable characteristics as low dark current and minimal after-pulsing from regeneration. However, plateau characteristics depend also on many parameters that are not pertinent to application. For example, the strong dependence on photomultiplier gain leads to changes in plateau length by a factor of two that have no practical importance.

The trend today is toward differential counting with pulse-height analyzers. This is a more reliable technique; it provides more precise analytical information; and it is a more fundamental measure of photomultiplier operation. For this technique the important parameter is pulse-height resolution. The choice between plateaus and resolution for performance evaluation of photomultipliers is important in establishing industry standards. (See box on page 74.)

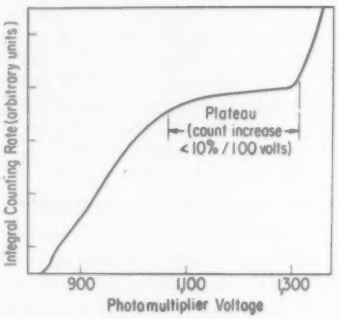

FIG. 1. Typical plateau is defined as portion of integral-bias characteristic in which change of counting rate per 100-volt interval is less than a selected value. Taking "slope" over finite intervals results in different true slopes at ends of plateau

Natures of Plateaus

Detailed analysis shows considerable difference between G-M plateaus and those of scintillation counters. The G-M plateau is a true saturation; this is not so clearly true with a scintillation counter.

In gas-filled counters, when the anode potential is near zero, only an event that deposits a large amount of energy in the gas creates a pulse large enough to be recognized. Each pulse has a magnitude proportional to the total number of ion pairs produced in the gas. As the potential is increased, there is a range over which this condition holds and the tube acts as a proportional counter.

Eventually a potential is reached at which gas multiplication sets in. Events that make enough ion pairs produce pulses of a maximum size determined by external or internal quenching. Counting rate continues to increase with increasing potential until all ionizing events trigger the tube completely. Pulses are all of maximum size, and no further counts are produced with increasing potential. The counting-rate-against-voltage curve has rounded the knee and reached the plateau.

With further increase of potential, the plateau comes to an end and counting rate increases once again. This is caused by double pulsing, in which a few ions remain after quenching and cause a second pulse from a single primary ionizing event. Thus length and flatness of a plateau indicate the absence of a tendency of the counter to double-pulse. Operation on the plateau assures the user that he is (1) counting all events and (2) avoiding counting any event twice.

In scintillation counters one must look for relationships among photomultiplier gain, crystal size and type, analyzer bias, radiation source and nature of surrounding scattering material. A typical measure of plateau is the range of supply voltage over which a photomultiplier can be operated with a sodium-iodide crystal and a Cs^{137} source so that the slope of the integral-bias counting rate as a function of voltage is less than some specified amount. For example, this can be taken as 10% per 100-volt interval. This is illustrated by the experimental plateau characteristic in Fig. 1. The high-voltage end of the plateau can also be defined as the voltage at which dark count has risen to some specified fraction of the plateau count.

For comparison with the plateau characteristic, Fig. 2 shows a pulse-height distribution obtained with a differential discriminator. A Cs^{137} source, a NaI(Tl) crystal, and an RCA 6342-A photomultiplier were used. The 6342-A is the commercial version of the developmental photomultiplier RCA Dev. No. C-7164G, described by W. Widmaier at the January, 1958, Scintillation Counter Symposium. It is an improved 6342 with a curved inner faceplate that contributes to better electron efficiency and better pulse-height resolution. The tube also has an additional shield that prevents feedback and permits higher-voltage

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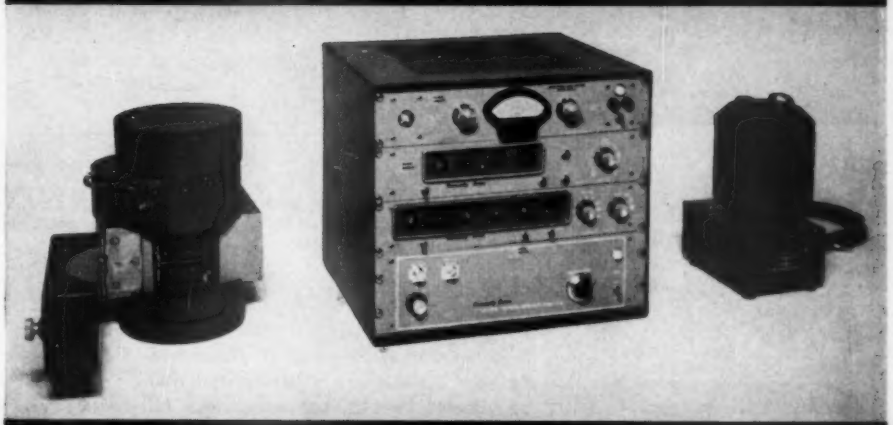

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Instrumentation for Better Analysis

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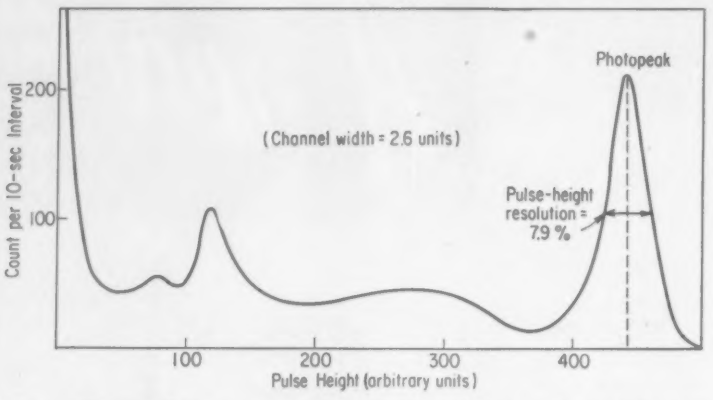

FIG. 2. Differential bias permits evaluation of pulse-height resolution, defined as width of photopeak at half maximum divided by pulse height at peak. This is typical pulse-height distribution

operation with smaller dark current. This produces a longer plateau.

A common measure of photomultiplier performance is pulse-height resolution. This is defined as the full width of the photopeak at half maximum divided by the pulse height at the peak. Pulse-height resolution depends on both crystal and photomultiplier properties. However, an independent measure of photomultiplier statistics can be made with constant-magnitude light pulses from a pulsed cathode-ray tube such as RCA Dev. No. C-73687A. Sharp resolution requires good statistics in conversion of light pulses to electrical ones. Pertinent photomultiplier characteristics are cathode sensitivity, collection efficiency at the first dynode for electrons emitted by the cathode, and uniformity of cathode sensitivity. Dark current caused by single electrons from the photocathode is not important in view of the usual large number of photoelectrons per scintillation pulse.

Derivation of Plateau

An analysis of the relationship between the pulse-height distribution of Fig. 2 and the plateau curve of Fig. 1 indicates how one can be derived from the other. First, the integral-bias characteristic curve of Fig. 3 can be derived by integrating the data of Fig. 2 from right to left. The small plateau at the right of Fig. 3 is determined principally by the depth and width of the valley to the left of the photopeak in Fig. 2. Thus it is closely related to pulse-height resolution, but it does not correspond to the plateau of Fig. 1.

In fact the plateau that is the subject of this paper does not appear in Fig. 3. It is related to the region of the curve near zero pulse height.

Derived plateau curve. A plateau curve can be derived from the integral-bias curve of Fig. 3 by expressing the integral count as a function of photomultiplier voltage instead of pulse height. The required relation between the marginal pulse height that just passes the bias and photomultiplier voltage can be obtained in two steps. First, a reciprocal relation is established between pulse height and current amplification or photomultiplier gain. Second, gain as a function of photomultiplier voltage is used to translate pulse height to a photomultiplier-voltage scale.

The height of the voltage pulse presented to the discriminator is proportional to the product of the size of the light pulse from the crystal and photomultiplier gain. Thus for a constant bias the pulse that is just accepted as marginal by the discriminator is described by the following equation: light-pulse height times photomultiplier gain equals a constant. Since the discriminator level is set arbitrarily, the constant can also be assigned arbitrarily to fit reasonable values of pulse height and gain. For example, let the maximum abscissa value of 500 in Fig. 2 represent that light-pulse height that corresponds to a minimum photomultiplier gain of 3,000. The arbitrary constant is thus 1.5×10^6. Fixing the constant in our equation establishes the reciprocal relation between pulse height and photomultiplier gain.

The necessary relation between pho-

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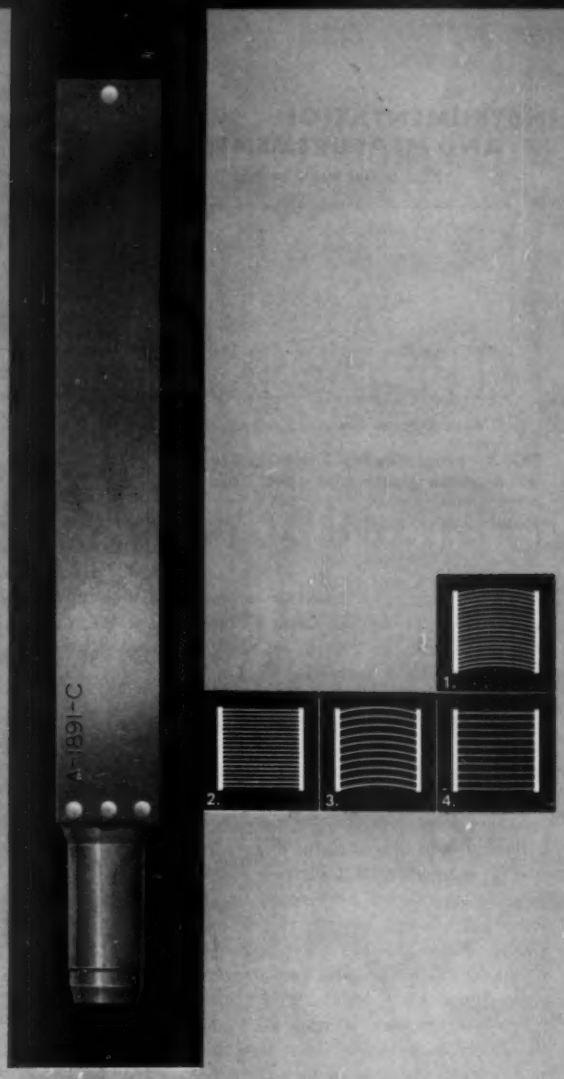

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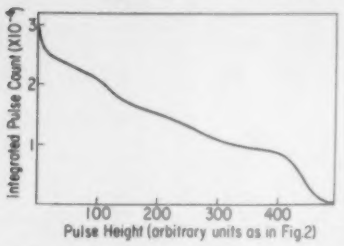


FIG. 3. Integrating Fig. 2 from right to left produces integral-bias curve. This curve is related to Fig. 1 but has different abscissa parameter

tomultiplier gain and voltage is obtained from published data. These data are shown in Fig. 4 for photomultipliers 6655A and 6342A. Gain is shown on a reciprocal scale to facilitate conversion to corresponding pulse height. Pulse-height values are also indicated on Fig. 4 in accordance with the relation just established between pulse height and gain.

The integral-bias curve of Fig. 3 can now be converted to a plateau curve by using the relation between marginal pulse height and supply voltage of Fig. 4. Figure 5 shows derived plateau curves for the 6655A with cesium-antimony dynodes and for the 6342A with silver-magnesium dynodes. Both curves are included to show how the more rapidly rising secondary-emission characteristic of cesium antimony results in a shortened plateau as compared with a silver-magnesium-dynode photomultiplier.

Interpretation

The resulting curves of Fig. 5 do not show a rise at high anode potentials as does the experimental curve of Fig. 1. This is because the pulse-height distribution curve of Fig. 2 was plotted for a moderate photomultiplier voltage so that no appreciable regeneration occurred. Since regeneration is a function of tube gain, arbitrary terminations have been indicated in Fig. 5 at gains of 10^6.

There is a close correspondence between the derived 6342-A curve and the experimental one. The derived plateau for the 6655A is only half as long as that of the 6342A because the gain of the 6655A increases more rapidly with voltage as shown in Fig. 4. Both plateaus in Fig. 5 extend over voltage ranges that correspond to pulse heights

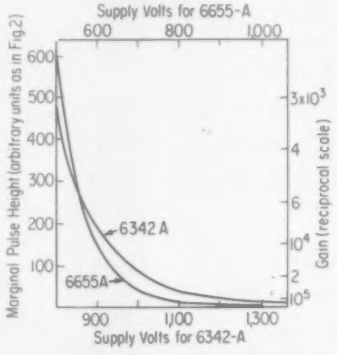


FIG. 4. Gain characteristics of 6655A and 6342A show marginal voltage-pulse height as function of anode voltage. Relation between pulse height and gain permits addition of gain scale. Flattening near zero pulse height determines plateau length

between 1.5 and 75 on the scale of Fig. 2. The major portion of the integral-bias curve is compressed into the region below the knee of the plateau curve. The minor flattening in the middle of the rise to the left of the plateau of Fig. 5 corresponds to the valley at the left of the photopeak of Fig. 2.

Significance

A long plateau provides latitude in both the voltage setting and the drifts in power supply and photomultiplier sensitivity. For modern, well-designed power supplies voltage drift is negligible. However, photomultiplier gain changes during tube life. Thus any plateau-length requirement for scintillation counters should be judged by the amount of change in gain that can be tolerated. In this respect, both the short plateau of the 6655-A and the long plateau of the 6342-A in Fig. 5 are of equal value.

A more universal plateau curve can be drawn in which the abscissa is the logarithm of photomultiplier sensitivity instead of applied voltage. Because such a curve is not practical for the average user, a rule of thumb that provides equal reliability is to require photomultipliers with cesium-antimony dynodes to have only half the plateau length of corresponding tubes with silver-magnesium dynodes. If plateau length were the only important parameter of photomultipliers relating to integral-bias scintillation counting, tubes could be designed with fewer

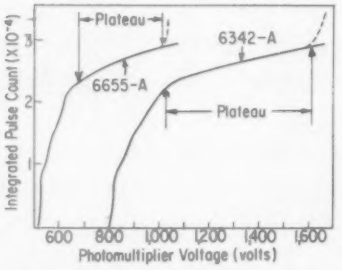


FIG. 5. Taking gain into account permits deriving plateau curves that correspond to experimental ones. Sharp rise caused by regeneration has been inserted at gain of 10^6

stages and operated with stage voltage nearer the maximum for secondary emission. Alternatively tubes could be made with dynodes of lower gain than that of silver-magnesium. However, the advantage of high gain at reasonable voltage would be lost.

What Is the Choice for an Industry Standard?

Scintillation counting plateaus depend on crystal size, radiation source and background scattering as well as the counting performances of photomultipliers. Thus it does not seem wise to try to provide an industry-standard plateau measurement. It is better to put more emphasis on primary factors that determine the usefulness of photomultipliers in scintillation counting. Among these are:

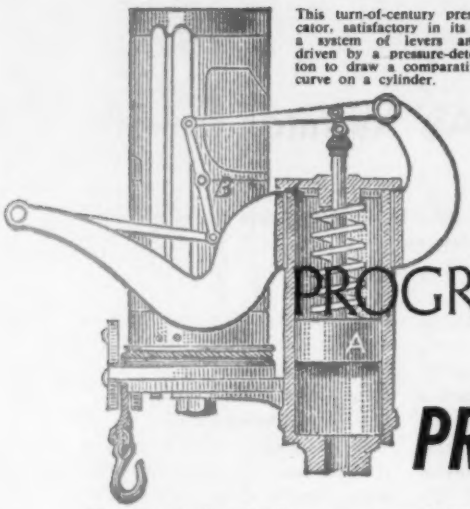
***Good stability*—to minimize sensitivity change in the integral counter.**

***Low dark current and low feedback at high gain*—to provide wide operating-voltage range. This is indicated by a flat equivalent-anode-dark-current characteristic. Equivalent-anode-dark-current input is the amount of light at the photocathode that causes an output current equal to the dark current. A typical display characteristic shows this input as a function of photomultiplier sensitivity.**

***High gain*—to provide minimum power-supply requirement.**

***High cathode sensitivity and good electron-collection efficiency*—to provide good statistics required for good pulse-height resolution and, to a smaller extent, a more clearly defined operating voltage.**

The trend today is toward the more reliable technique of differential counting. For this purpose the important parameter is pulse-height resolution.



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PROGRESS IN MEASUREMENT

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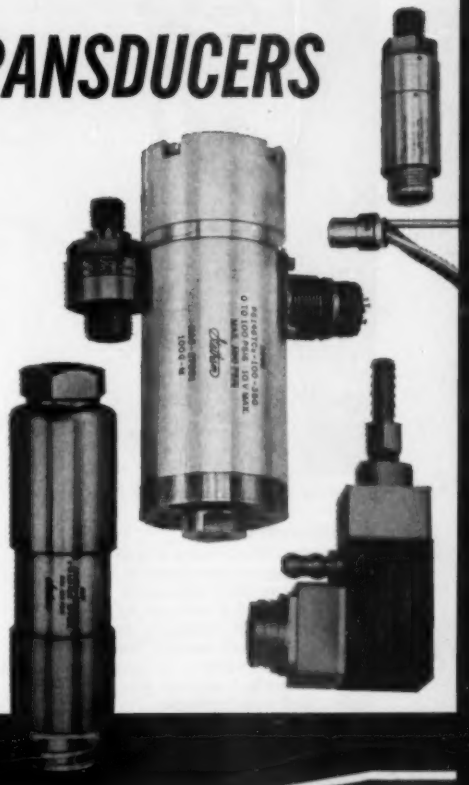

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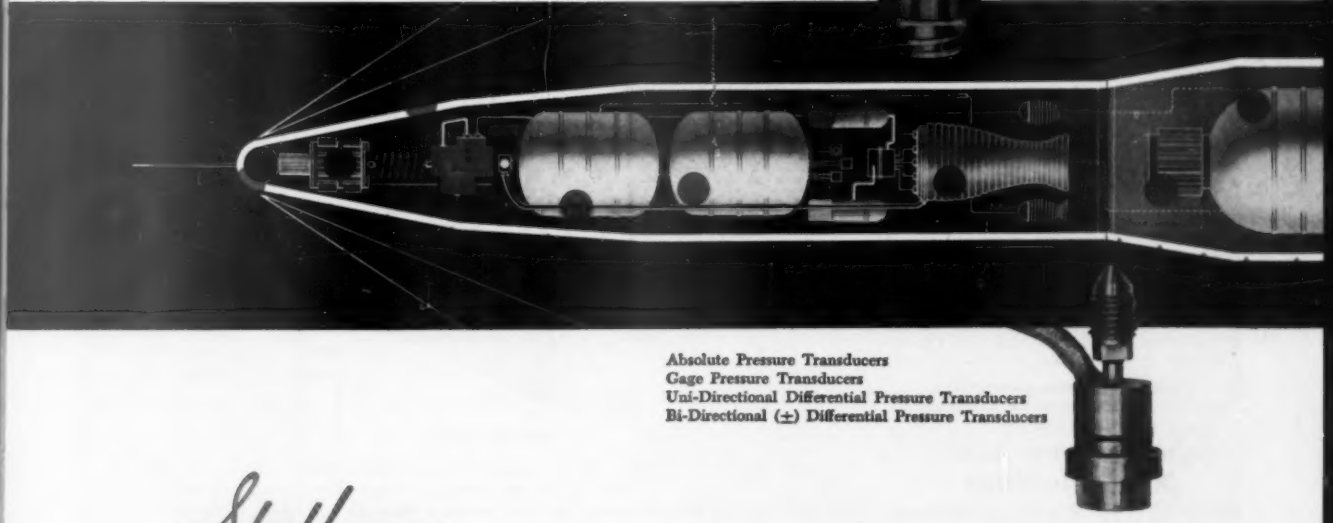

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Continuous Air Monitor for H^3

By J. BRINKERHOFF, C. A. ZIEGLER, R. BERSIN and D. J. CHLECK
Tracerlab Inc., Waltham, Massachusetts

In areas where tritium or tritiated water of high specific activity are used, a routine check on air contamination is necessary. We have developed a continuous monitor capable of accurately indicating tritium concentrations of 0.1–100 times the maximum permissible concentration [2×10^{-5} $\mu c/cm^3$ (*1*)] with an estimated error over the range not exceeding $\pm 5\%$. The instrument uses a flow-type ionization chamber (see illustration).

Two general types of monitor have been previously developed to meet this need. The first type, exemplified by the Los Alamos "Sniffer" (*2*), is also a flow-type ionization chamber—sampled air flows through an open-ended chamber. Its response is unreliable mainly because of sensitivity to spurious ionization.

The second type uses a particle counter. Sampled air mixed with counting gas is passed through a windowless flow counter where the ionizing events occurring in the sensitive volume of the counter are counted. A monitor of this type is reportedly capable of detecting tritium concentrations as low as the maximum permissible concentration (MPC) (*3*). However, it is also sensitive to spurious counts, and the well regulated gas supply required entails a cumbersome device.

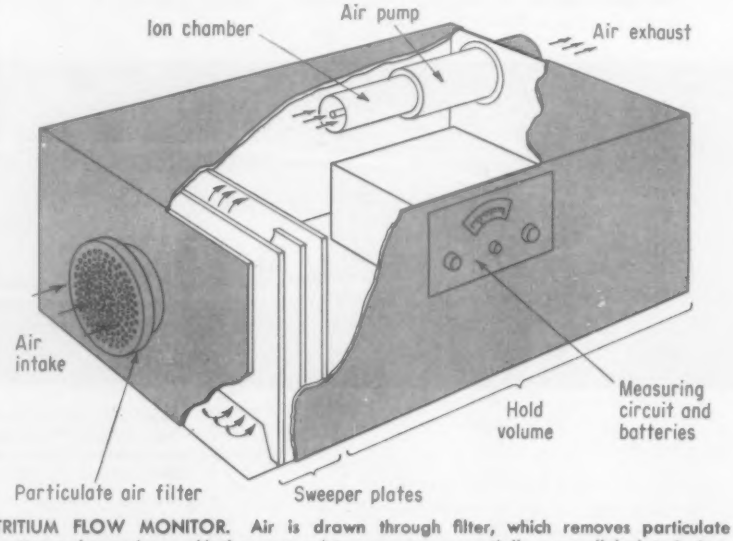
Being of the first type, our monitor avoids the complexity and bulk of the particle counter. However, by means of a filter and ion-sweeper system, it is unresponsive to airborne sources of ionization other than radioactive gases.

Theory of Operation

Let us assume a concentration of tritium in air of C $\mu c/ml$. The number of ion pairs formed per unit volume per second, n_0, will be

$$n_0 = C(3.7 \times 10^4)\bar{E}/33 \qquad (1)$$

where $\bar{E}$ is the average energy of the beta particle (6,000 ev for tritium). If R is the number of recombinations



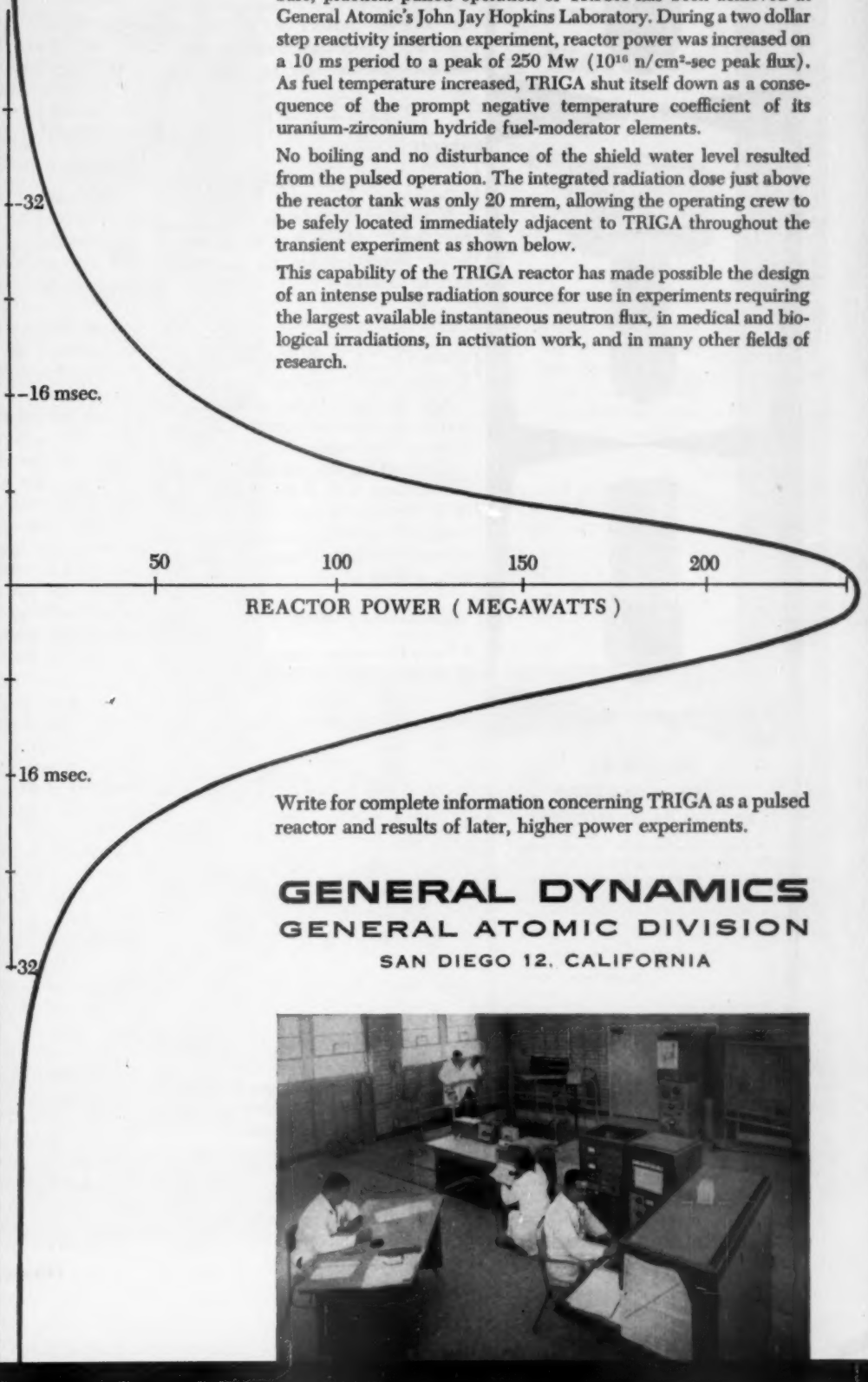
TRITIUM FLOW MONITOR. Air is drawn through filter, which removes particulate matter and some ions. Air then passes into sweeper—essentially a parallel-plate ionization chamber—where remaining ions are removed from air. Ion-free air passes from sweeper into hold volume, where ionization occurs if radioactive gas is present. Flow rate is such that virtually all ions formed in hold volume pass into ionization chamber before recombination can occur. Total volume of unit is ~4 ft^3

TRIGA
Pulsed Reactor

Safe, practical pulsed operation of TRIGA has been achieved at General Atomic's John Jay Hopkins Laboratory. During a two dollar step reactivity insertion experiment, reactor power was increased on a 10 ms period to a peak of 250 Mw (10^{16} n/cm²-sec peak flux). As fuel temperature increased, TRIGA shut itself down as a consequence of the prompt negative temperature coefficient of its uranium-zirconium hydride fuel-moderator elements.

No boiling and no disturbance of the shield water level resulted from the pulsed operation. The integrated radiation dose just above the reactor tank was only 20 mrem, allowing the operating crew to be safely located immediately adjacent to TRIGA throughout the transient experiment as shown below.

This capability of the TRIGA reactor has made possible the design of an intense pulse radiation source for use in experiments requiring the largest available instantaneous neutron flux, in medical and biological irradiations, in activation work, and in many other fields of research.



Write for complete information concerning TRIGA as a pulsed reactor and results of later, higher power experiments.

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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 76

per second per unit volume, then

$$R = Bn^2 \qquad (2)$$

where B is the recombination constant and n is the number of ions per unit volume. The change in the number of ion pairs present may be represented as

$$dn/dt = n_0 - Bn^2 \qquad (3)$$

whence

$$n = \sqrt{n_0/B} \tanh \sqrt{n_0 B}\, t \qquad (4)$$

If most of the ions are swept from the "hold" volume into the chamber before recombination, the maximum current possible is

$$I_M = n_0 eV \qquad (5)$$

where $e = 1.6 \times 10^{-19}$ coulomb, and V is the "hold" volume (in practice V is large compared to the volume of the ionization chamber proper, so the latter will be neglected).

If we set up the condition that we will measure 0.98 of the ions created in V, then the ratio of the measured ionization current to the maximum obtainable ionization current will be $I/I_M = 0.98$, where

$$I = neF \qquad (6)$$

F being the volume flow rate of the air through the system (the pressure remaining at 1 atmosphere). Substituting Eq. 4 for n gives the ratio

$$\frac{I}{I_M} = \frac{F}{n_0 V}\sqrt{\frac{n_0}{B}} \tanh \sqrt{n_0 B}\, t \qquad (7)$$

Substituting $Ft = V$ and rearranging

$$\frac{I}{I_M} = \frac{F}{V\sqrt{n_0 B}} \tanh \frac{V\sqrt{n_0 B}}{F} \qquad (8)$$

If we require $I/I_M \geq 0.98$, then

$$\frac{F}{V\sqrt{n_0 B}} \geq 4 \text{ or } F \geq 4V\sqrt{n_0 B} \qquad (9)$$

In practice, a flow rate is maintained such that I is of the order of 0.98 I_M, since increasing the flow rate further would require greater collection voltages on sweeper and chamber with little gain in sensitivity o stability.

With these equations, it is possible to design the system. Before proceeding to actual design considerations, however, it is important to emphasize certain points regarding the response of the instrument. The measured ionization current is directly proportional to the tritium concentration in the air, C: $I = I_M = CK$. The constant $K = (3.7 \times 10^4/33)\bar{E}eV$.

The measured response is independent of the recombination constant (which may vary with temperature, humidity, etc.). Moreover, since the air that enters the "hold" volume is ion-free (by virtue of the filter and ion sweeper), the response is not affected by sources of ions other than radioactive gases.

Instrument Design

The monitor uses a cylindrical collection chamber of 9.8-cm i.d. and 28-cm length.

A conventional electrometer circuit measures the current. Full scale on the lowest scale is $\sim 10^{-12}$ ampere, with the middle scale 10 times and the highest scale 100 times this value.

With $I = n_0 eV$, the hold volume required for a sensitivity of 10^{-12} ampere for the MPC of tritium in air (2×10^{-5} μc/cm³) is 46 liters. For 98% collection efficiency on the least sensitive scale and $B = 1.6 \times 10^{-6}$/sec/ion pair/cm³, a value for F of 27 liters/sec was calculated. Thus, a substantially linear relation between ionization current and tritium concentration can be maintained up to a concentration of 100 × MPC, and the system will detect the tritium MPC as full scale on the lowest scale.

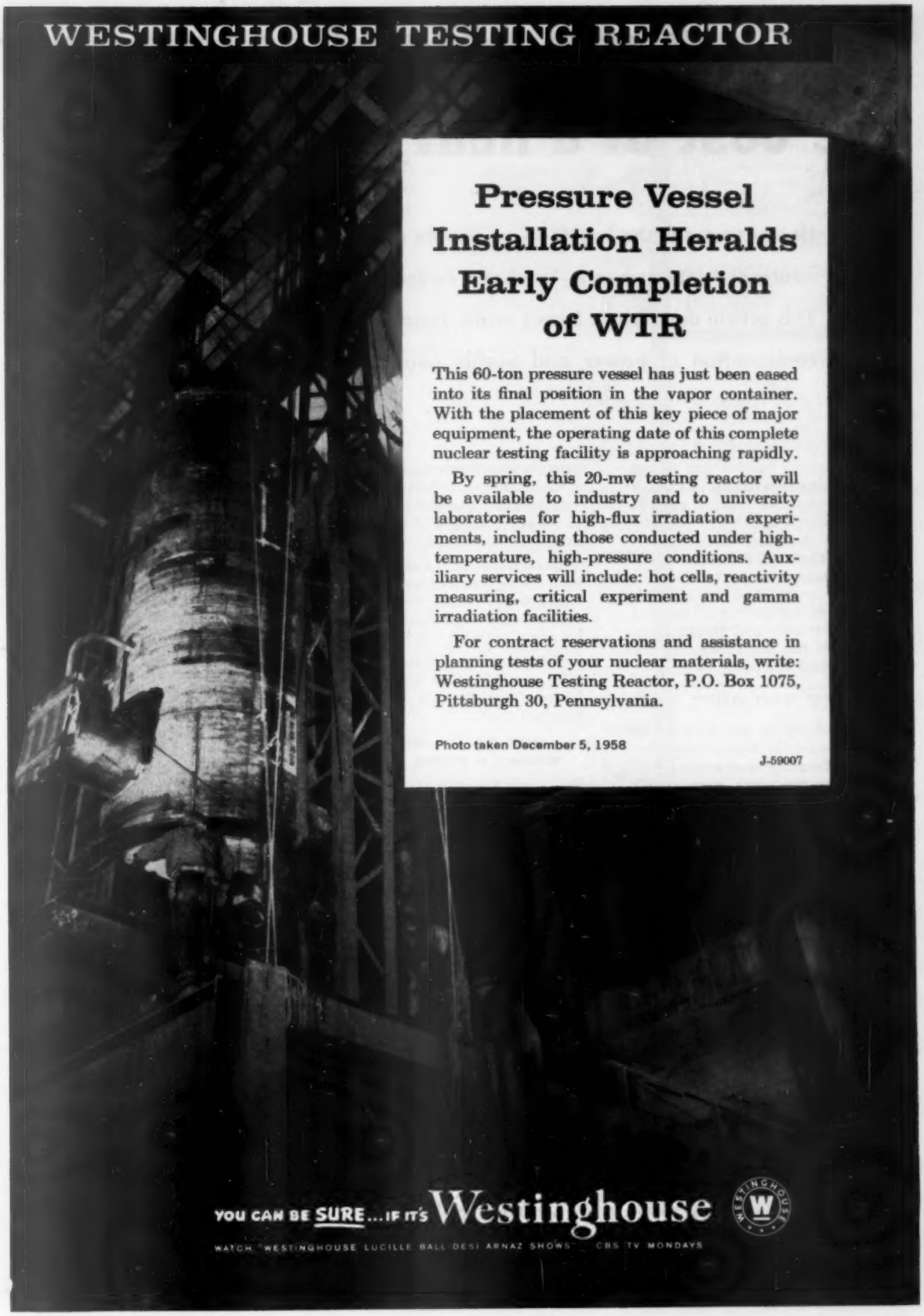
A compact high-speed, heavy-duty, turbine-type air pump designed for 24-hr sampling provides the required flow rate through a particulate-removing filter. A parallel-plate ion sweeper is operated at 600 volts, this value being satisfactory up to ion concentrations of ~1 esu/cm³. A voltage of 100 volts is sufficient for the collection chamber proper.

When the instrument was operated with the sweeper alone, i.e., no intake particulate filter, a large response ($>10^{-10}$ ampere) was produced. This was eliminated upon filtering the input air, indicating that spurious instrument response was largely due to charged particulate matter. TFA type "S" pleated filter* provides satisfactory filtration with minimum resistance to air flow. This combined filter-sweeper renders the instrument insensitive to any external ionization of the air encountered in normal usage.

(*Cont.*)

* Staplex Co., Brooklyn, N. Y.

WESTINGHOUSE TESTING REACTOR



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WHY HEAVY WATER?

The *initial* capital cost of a heavy water reactor is higher than for types differently moderated. But, to produce the same, high usable flux levels heavy water makes possible would require 2 to 3 times the capital investment if other moderators were used. The chief reason is... heavy water's low neutron absorption which makes more neutrons available for leakage into experimental facilities. Other factors also contribute to the superiority of heavy water reactors.

For example, heavy water assures long neutron lifetime, thus safer operation and thus savings in containment requirements.

Further, heavy water means minimum absorption in the reflector region, contributing to high thermal flux peaking. Because of the large thermal diffusion length of heavy water, thermal flux decreases gradually so that high fluxes can be brought to bear over large experimental volume. Both these factors contribute to economical attainment of design objectives.

Leakage neutrons have a greater probability of finding their way into the experiment...compared to a light water reflector, a much smaller percentage of leakage neutrons are absorbed in the reflector or lost in the shield.

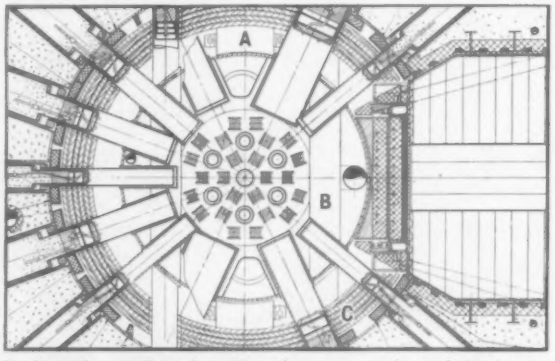
In short, in terms of reactor design for a given flux level, the physics of heavy water for moderator and reflector expresses itself as... economy.

Finally, an important non-scientific contribution to economy: heavy water can now be leased at nominal rates.

WHY THE AMF UNIVERSAL RESEARCH & TESTING REACTOR?

First, it is the only design that can satisfy the customer who wants a full range of nuclear research and testing facilities in one reactor. Costly multiple installations are eliminated, including multiple containment structures and costly associated mechanical equipment. This 10MW (or higher) reactor offers over 30 radiation facilities of which 11 are beam tubes with entry fluxes as high as 5×10^{14} nv thermal (slightly lower *for epithermal*)...a reactor that serves practically every research and testing purpose. The capital economies it makes possible are enormous.

It can operate up to 30MW without modification and without maintenance difficulties. The problems encountered at prolonged operation at 5MW or more with reflectors such as graphite are eliminated by use of a light water and laminated-steel thermal shield.



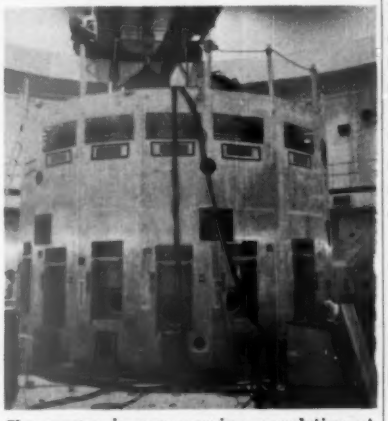
A. Light water
B. D_2O
C. Laminated-steel thermal shield

Epithermal as well as thermal neutrons are made available by re-entrant tubes in AMF Atomic's Universal Research & Testing Reactor. Facilities include: 11 high flux beam tubes, 4 to 11 inches in diameter; 1 central core thimble; 8 vertical thimbles into reflector; 2 grazing tubes; 2 isotope trains; 4 pneumatic rabbits; 1 thermal column.

Another example of AMF Atomics

CLEAN MECHANICAL DESIGN

Liquid moderators have led to piping and control designs which are extremely costly to install, maintain and work around. AMF's many years of solving complex mechanical and hydraulic problems... for a wide range of industrial applications... have produced an exceptionally clean mechanical design in this reactor. In addition, control rod drives are AMF's proven design. The rods are latched magnetically within the core vessel eliminating the problems of scramming through a seal.



The reactor is now nearing completion at Tokai Mura, Japan. Note absence of complex piping, simplicity of mechanical design.

The reactor is easy to install and disassemble for maintenance... again contributing to economy. Mechanisms and drives are located outside the biological shielding for easy access.

Refueling is accomplished with a simple, manually operated machine that greatly reduces risks in handling of spent fuel.

16TH RESEARCH REACTOR UNDER CONSTRUCTION

AMF Atomics is presently building its 16th research reactor. All this experience has been applied in the design of the UNIVERSAL RESEARCH AND TESTING REACTOR. The first installation will soon go critical at Tokai Mura, Japan and will be the main research tool of the Japan Atomic Energy Research Institute.

AMF Atomics, 140 Greenwich Avenue, Greenwich, Connecticut.

AMF

experience at work

INSTRUMENTATION AND MEASUREMENTS

This article starts on page 76

Testing and Calibration

Gamma rays were used to calibrate the instrument and to test operation. The dose rate corresponding to the MPC for tritium is 0.23 mr/hr. With predicted values of flow rate and with the hold volume in a uniform gamma field of 0.23 mr/hr, the instrument gave an indication corresponding very closely to the predicted value of 10^{-12} ampere, i.e., full scale for the tritium MPC. The system response was also observed to be linear up to concentrations corresponding to 100 times this value.

It was brought to our attention that the "Sniffer" flow-type ionization chamber utilizing a paper filter showed erroneous tritium concentrations in an environment containing tritiated water vapor due to buildup of water vapor on the filter (*4*). This effect has not been noted in our instrument, probably because much higher flow rates are used.

Background Response

When the system is in operation, it is equivalent in sensitivity to a saturated static ion chamber of volume equal to the "hold" volume (in this case 46 liters). This, of course, makes it sensitive to external radiation.

In operation, the system records external background radiation as about $\frac{1}{25}$ of the response to the MPC of tritium, or about 0.01 mr/hr, corresponding to the value ordinarily encountered. This sensitivity makes it unsuitable, in its present form at least, for use in strong gamma fields. It is possible, however, to use a separate pressurized static chamber to cancel out external radiation effects.

Other Applications

The monitor can be adapted to measure radioactive gases other than tritium. It can also be used as a sampler for particulate airborne material. It is possible to monitor large objects for surface contamination by inserting them into the hold volume.

BIBLIOGRAPHY

1. Handbook 52 (National Bureau of Standards, U. S. Department of Commerce, Washington, D. C., 1953); since publication of this handbook, the value has been raised to 2.5 × 10^{-5} $\mu c/cm^2$
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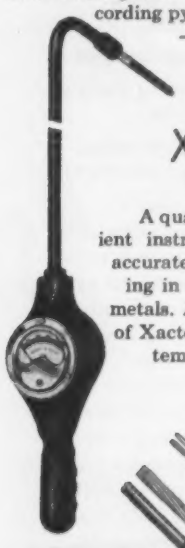

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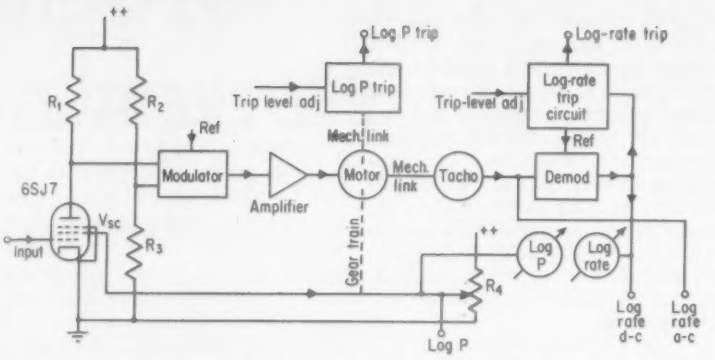

FIG. 1. Operation of period meter. Input current unbalances bridge formed by pentode, R_1, R_2 and R_3; a-c signal from modulator changes position of potentiometer R_4 through servomotor until bridge is balanced through screen-grid connection of R_4. Reactor power level is indicated by V_{sc} or R_4 position. Log P trip device can be geared to R_4 shaft. Second potentiometer mechanically linked to R_4 provides isolated log P output for control or recording. Tachometer output, proportional to dV_{sc}/dt, is fed to phase-sensitive detector (or ring demodulator), which gives output only when reactor power increases; output is sufficient for recording, control and tripping reactor. Ring-type modulator, using silicon diodes, responds to signals of $\sim 5 \times 10^{-9}$ amperes. Transistorized servoamplifier consists of two class A stages followed by push-pull driver stage and push-pull class B output stage; power transistors are coupled to servomotor control field

Logarithmic-Amplifier Period Meter

By A. PEARSON

Atomic Energy of Canada, Ltd., Chalk River, Ontario, Canada

and Y. J. FOKKINGA*

Sperry Gyroscope Company of Canada, Ltd., St. Laurent, Quebec, Canada

The reactor-period instrumentation described here is completely transistorized except for one vacuum tube serving as the logarithmic element. An electromechanical servo loop provides an isolated logarithmic output signal, and a tachometer linked to the servomotor provides a log-rate or period signal.

The device can be used for the following applications:

1. Monitoring log power and log rate during reactor startup without range switching.

2. Reactor control during part of the startup cycle for reactors with automatic startup and, if made linear in the reactor operating range, control in that range.

3. Gamma monitoring if combined with a suitable ion chamber; an ionization chamber has better calibration than a scintillation photomultiplier. Intense radiation causes spurious signals in a photomultiplier but not in an ionization chamber.

4. Service as a simple reactor simulator if modified to obtain the antilogarithm of an input. To accomplish this, the servo system would control the grid current and produce an isolated signal proportional to this current while the input is applied to the screen grid.

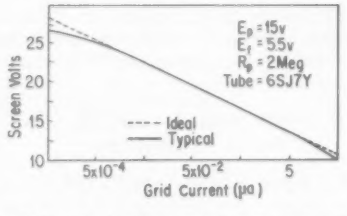

FIG. 2. Typical logarithmic output signal

Over-all Design

This design makes use of a pentode

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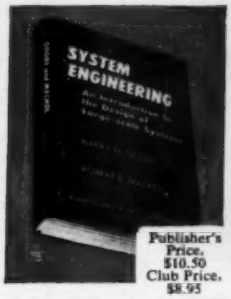

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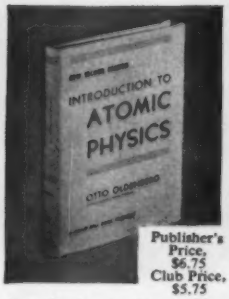

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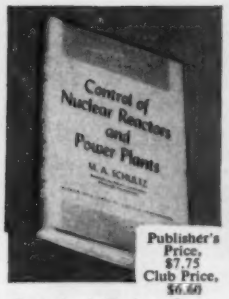

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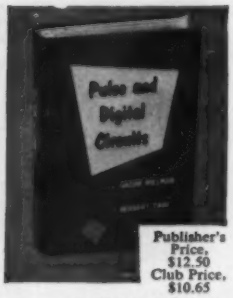

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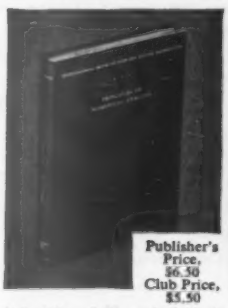

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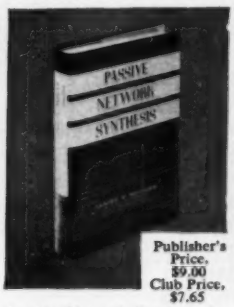

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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 82

Meter Specifications

Range: 5×10^{-5}–25 μa

Logarithmic output: ~3 volts/decade taken from screen grid (or in shaft rotation, ~10 rad/decade); output from separate potentiometer may be much higher

Logarithmic rate: 0–10%/sec

Logarithmic rate output: Depends on tachometer type used

Trips: (a) Cam-controlled switch set at any power level within range of instrument. (b) Transistor trigger circuit set to fire at any value of logarithmic rate within range of instrument; alternatively, magnetic amplifier can be used

in which the plate current is held constant by feedback to the screen grid by a servo-driven potentiometer, the servo system responding to deviations of the plate current (*1–4*). Since the gain ratio G between control grid and screen grid can be assumed constant over the range under consideration, the screen-grid voltage will vary proportionally to the logarithm of the control-grid current. The servomotor-drive tachometer gives an output signal proportional to the rate of change of the screen-grid voltage and is thus proportional to the logarithmic rate. The arrangement is shown in Fig. 1.

The use of the pentode as both diode and amplifier has two advantages over a separate diode followed by an electrometer-type amplifier tube: (a) The influence of cathode thermopotentials is reduced by a factor of G. (b) Variations in cathode temperature cause opposing effects on the cathode-grid and cathode-plate relations and thus tend to cancel out.

The electromechanical servo loop offers several possibilities: (a) A mechanical log P indicator (or recorder) can be coupled directly to the gear train. (b) A cam and switch can be driven off the gear system to provide a reliable and adjustable power trip. (c) An isolated log P output can easily be obtained.

A true logarithmic output signal depends mainly on the logarithmic response of the vacuum tube and the lin-

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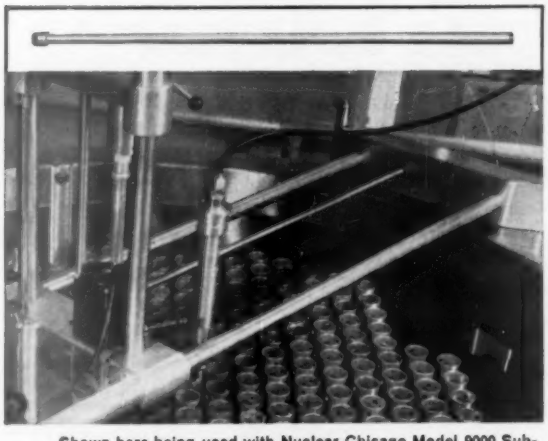

Shown here being used with Nuclear-Chicago Model 9000 Subcritical Training Reactor to measure slow neutron flux at various points in the lattice, neutron probes are 42" long and are available in two diameters, 3/4" and 11/32".

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INSTRUMENTATION AND MEASUREMENTS

This article starts on page 82

earity of the multiturn potentiometer.

A typical nI_g *vs.* V_{sc} curve is shown in Fig. 2. The deviation of the curve from a straight line for low input currents is due to leakage and positive ion current. Biasing of the control grid corrects for the decreasing slope in this region. The increasing slope of the curve in the high-current region can be corrected by padding the multiturn potentiometer. By further padding of the potentiometer, it would be possible to change the curve so much in the high-current region that the instrument would respond linearly to the input signal. The rate output in this part of the range would then become the linear rate instead of the logarithmic rate.

Circuit Details

The vacuum-tube logarithmic device and its associated circuitry are shown in Fig. 3.

The connection of the log P meter between the screen grid and an adjustable reference voltage, which allows zero-setting the meter for minimum input signal, is a temporary arrangement. Ultimately, a more robust and accurate mechanical indicator with expanded scale connected to the potentiometer will be used.

In the present model, a phase-sensitive demodulator, giving an output only when the log power is increasing, is employed. Its circuit is shown in Fig. 4.

Test Results

The logarithmic response of the instrument and the differentiating circuit were checked with an exponential signal from an analog computer. As is inherent in this class of equipment, the response is somewhat sluggish at low input levels. This is caused by the capacitor across the input, which filters out undesired h-f pickup and ion-chamber fluctuations, together with the equivalent input resistance of the tube.

The sensitivity of the servo system is such that the correct screen-grid voltage is always obtained within about 2 mv for any input current within the range of the instrument. This error, or dead zone, is negligible compared with the 3-volt/decade output of the screen grid. The accuracy of the log P indication thus depends entirely on the tube characteristics and the constancy of the filament and supply voltages. Since the supply voltages are well-regulated, deviation from a true logarithmic output will depend only on aging effects and selection tolerances of the tube.

By means of the controls R_6 and R_5 (Fig. 3), the shape and the level of the ln $I_g - V_{sc}$ curves can be corrected. The curve can be corrected in the higher part of the range both by selecting tubes with close tolerances and by padding the screen-grid potentiometer. If the accuracy and reproducibility prove to be satisfactory, this instrument can take over the function of the linear-channel equipment. A saving in instruments and ionization chambers (and ion chamber space in the reactor) might be obtained.

Since a multiturn potentiometer with padding taps was not initially available, control-grid biasing was used for curve correction. This method alone

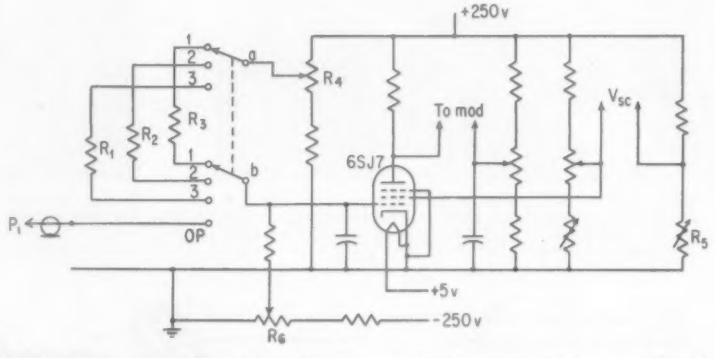

FIG. 3. Input circuit. Test input signal for calibration and checking is derived from circuit formed by R_4 and R_1, R_2 or R_3. Potentiometer R_6 bias to control grid corrects for low-current leakage and positive ion current. Pentode operation in lower ranges is stabilized by transistor-regulated d-c filament supply

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DC Current Gain h_{FE}			Gain X Bandwidth		Power Gain K_p		
2N602 2N603 2N604	$V_{CE} = 1$ v $I_B = 0.5$ ma	* 25-100	$V_{CB} = 5$ v $I_C = 5$ ma	10-30 mc 30-50 50-70	2N605 2N606 2N607 2N608	$V_{CB} = 7.5$ v $I_C = 1$ ma $f = 2$ mc	20-25 db 25-30 db 30-35 db 35-40 db

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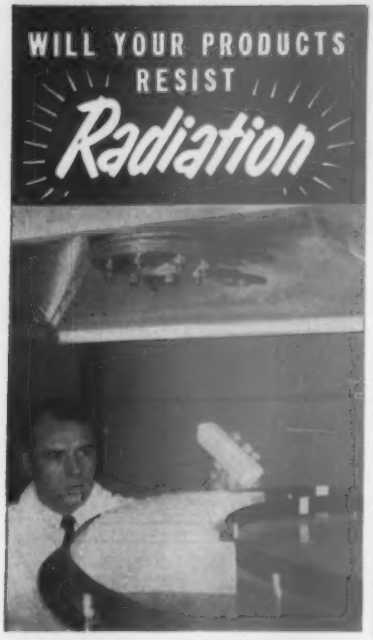

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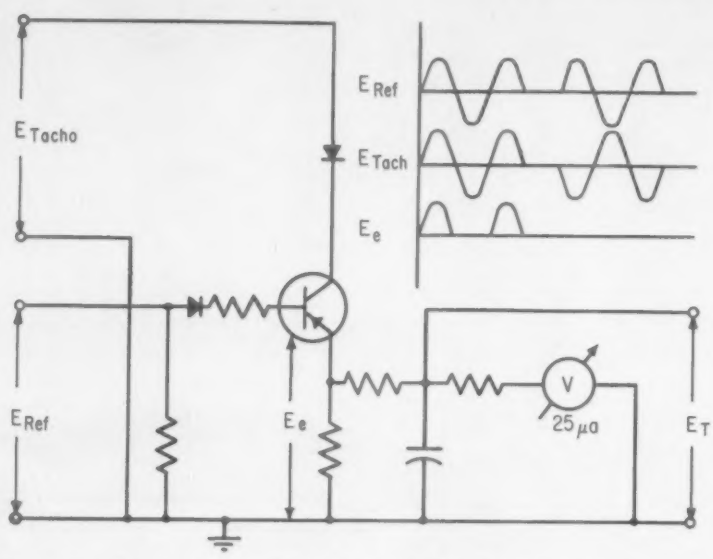

FIG 4. Demodulator circuit. With input and reference voltages in phase, output signal is proportional to input. Output is available for log-rate meter, reactor control, recording and log-rate trip circuit with increasing log power

brought the first part of the logarithmic conversion curve (Fig. 5) well within the correction limits. Results so far obtained indicate that the log P output signal will not deviate by more than 0.1 volt from the ideal curve.

Replacement of the 6SJ7 pentode by a Mullard ME1400 may yield even better results and increase the range of the instrument. In the lower range, the instrument is rather sluggish. Improvement has been obtained by connecting the control grid to the positive and negative sources through high resistances (10^{10} ohms each). In this way, a false zero is introduced and the time constant is reduced. Drifts of <10 mv in screen-grid voltage have been observed over periods up to 60 hr.

The log-rate accuracy depends on the tube characteristics and tachometer response. Small deviations from a logarithmic characteristic, of course, cause relatively large errors in the rate output. Apart from the highest part of the highest decade, the error did not exceed 10% of the "mid"-scale value. Screen-grid potentiometer padding and possibly the use of an ME1400 tube will reduce this error considerably.

Because of the low-frequency response of the electromechanical servo loop, the instrument is free from the microphonic effects and the long-duration transient errors due to large RC time constants that are usually encountered in this type of equipment.

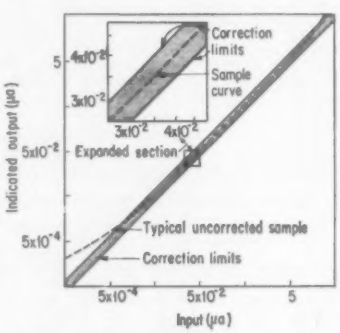

FIG. 5. Logarithmic conversion. Correction limits are based on assumption that log P output signal will not deviate from ideal curve by more than 0.1 volt. Deviations of sample curve from linearity are due to leakage at lower end and saturation at upper end. Magnified section of curve at upper left indicates magnitude of correction limits

* * *

The authors wish to express their gratitude to W. J. Riley (Chief Engineer, Sperry Gyroscope Company of Canada, Ltd.) for his encouragement to publish, and to J. R. G. Cox for his valuable criticism.

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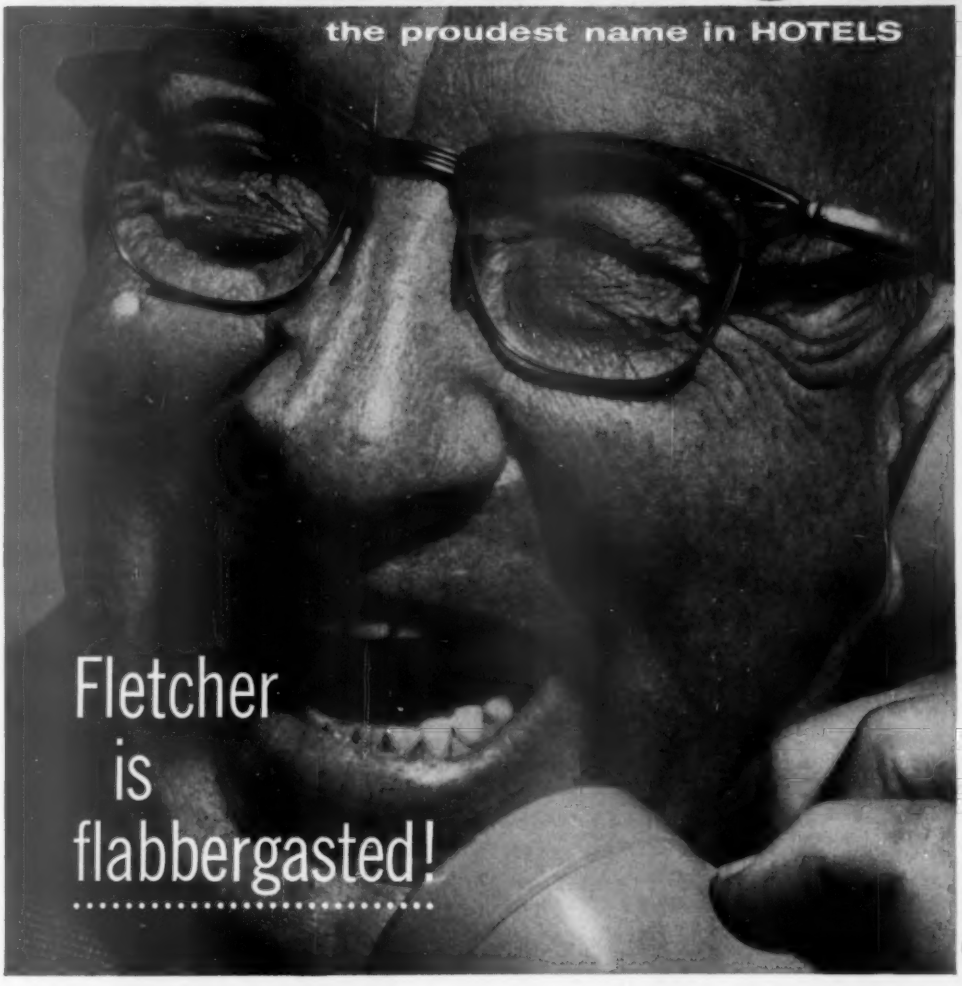

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DALLAS
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W. B. Lewis Reviews UO_2 Status

One of the pleasures of the winter meeting of the American Nuclear Society at Detroit in December was a luncheon talk given by W. B. Lewis (Atomic Energy of Canada Limited) on the subject of uranium dioxide. Following is a condensed version of his remarks:

"Uranium dioxide has emerged as the preferred reactor fuel both for enriched and for natural uranium reactors, not only for the water-cooled reactors such as Dresden, the Yankee and the Canadian D_2O reactors, but also for the advanced gas-cooled reactors designed in the United Kingdom and at Oak Ridge. Uranium dioxide also seems best for organic-moderated or -cooled reactors and even for some designs of sodium-cooled and fast reactors. Moreover, if superheated steam can be taken directly from the reactor to the turbine, again UO_2 heads the list as fuel.

"There are about half-a-dozen different major reasons for the choice, such as (1) corrosion resistance in water, (2) long burnup without swelling, (3) high melting point, (4) good safety by retention of fission products, (5) ease of processing, (6) low cost fabrication, (7) no neutron wastage.

"The main trouble with uranium dioxide is its very low heat conductiv-

A Pile Oscillator with Sample-Changing Features

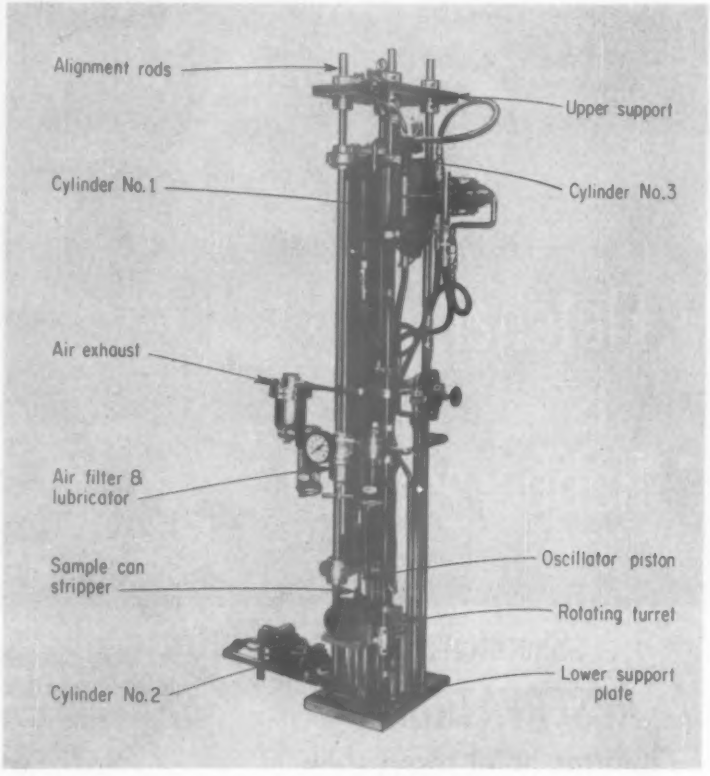
The pile oscillator shown here was developed to speed the gathering of data for a series of pile oscillation experiments that were conducted at the Argonne National Laboratory. Its design and construction, however, are such that it could be used in a variety of low power reactors or critical assemblies for pile oscillation or "danger coefficient" measurements. The instrument is capable of remotely changing up to twelve samples during a given run. Moreover, the samples are accurately positioned inside the reactor for each measurement.

The mechanism has four basic operations: the first is to raise and lower the sample to be oscillated in the reactor, the second is to detach the sample when the measurement has been completed, the third is to move another sample into position to be oscillated and the last is to attach the new sample to the oscillating assembly.

The samples are mounted in extruded thin-walled aluminum cans, each of which has a small aluminum ball mounted on the cap. This ball is grasped by a stainless steel clip attached to a slender aluminum rod. This rod is the piston of a 2-in.-i.d. pneumatic cylinder (No. 1 of figure) with a 32-in. stroke that is operated by dried and lubricated air. A four way solenoid valve controls the movement of the cylinder when signalled by the control unit.

The sample must be withdrawn from the guide tube and must be in its chamber in the turret before the next operation can be executed. When this condition is fulfilled, cylinder No. 2 moves a sliding panel out to prevent the sample from falling into the guide tube when the sample is detached from the clip. The sample can be detached from the clip by raising cylinder No. 1 by cylinder No. 3. This movement strips off the sample can and causes it to fall back into its chamber. The oscillator is now free to select another.

When cylinder No. 1 is in the raised position, the turret can be rotated. The drive motor is activated manually but is deactivated by a precisely positioned microswitch that exactly aligns the new chamber over the sample guide tube. A time-delay mechanism prevents the lowering of cylinder No. 1 until such time as the turret is in place. When the cylinder is lowered, the new sample is grasped by the clip, cylinder No. 2 is closed and the next oscillation can begin.—E. F. Groh, A. F. Engfer and R. A. Mattson



ity. Another problem facing the user is understanding and controlling the fission-product gases. The amount of fission-product gas is large; at 10,000 Mwd/tonne U, it would occupy at atmospheric pressure and room temperature 3 times the volume of the fuel. Otherwise expressed, if it is confined to a 5% void space at a temperature of 2,000° C, it would exert a pressure of 500 atm or 7,000 p.s.i.

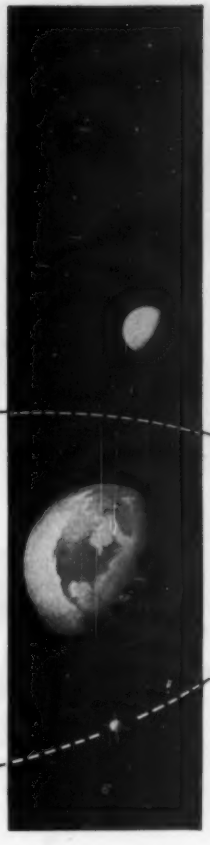
"It seems, however, unnecessary to take a view as pessimistic as supposing that all the fission gas is liberated. We have carried some fuel to over 5,000 Mwd/tonne at high power ratings with a release of only a few per cent of the fission gas produced. Trying to find how this gas is retained is leading us into some fascinating research.

"We already recognize the important changes in fuel properties brought about by a small excess of oxygen. When about 7% extra oxygen is incorporated in UO_2, the thermal conductivity drops by a factor of three, the density is slightly increased, the sintered oxide becomes plastic at 1,000° C, and under irradiation in round rods it recrystallizes in radial columnar crystals, right out along the radius to regions that must have been well cooled. It also releases more fission-product gas.

"This relates to a most remarkable property of UO_2 that has been known for some years. If it is sintered in steam at 1,400° C, the equilibrium concentration reached has this extra 7% of oxygen, but if as little as 5% of hydrogen is introduced into the steam atmosphere, the composition of a whole block of sintered oxide changes within an hour to the regular stoichiometric ratio of 2 oxygen atoms to 1 uranium atom. Such changes of atmosphere may occur in water-cooled reactors if a defect develops in the cladding and steam gets in. When the oxide takes up oxygen, an excess of hydrogen is left. From the engineers' point of view, the behavior is good because the oxide does not swell, but fission gases are liable to be released, and as the thermal conductivity goes down the oxide will get hotter. Qualitatively this seems certain, but no one has yet supplied the engineers with reliable quantitative data.

"Finally, from the behavior of thick UO_2 fuel rods under irradiation, we have a clue that hot UO_2 under irradiation may be plastic at lower temperatures than in laboratory experiments;

NEWS from OUTER SPACE



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plastic flow of irradiated UO_2 has in fact been shown in some intriguing micrographs by Barney of KAPL. What clearance and what strength of can should be specified? We have some results but it will take years to know with assurance."

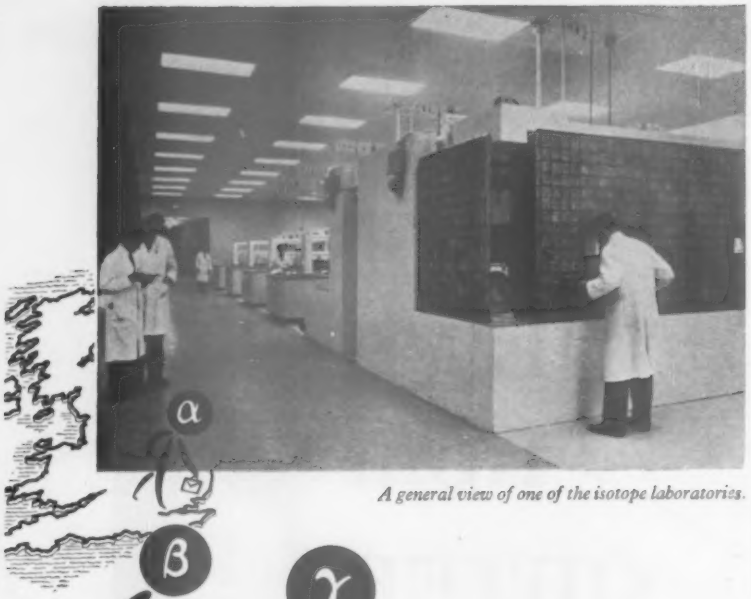
Other Meeting Highlights

η_{233} Higher Again. Does η, the ratio of neutrons produced to neutrons absorbed, have the value 2.28 or 2.19 for U^{233}? The high value is the one given in the most recent U. S. "barn book" (BNL 325) and the one reactor designers have been using in Th-breeder evaluations; the low value was reported at Geneva by H. Rose *et al.* (UK Geneva paper 14) as the result of some new oscillator experiments and would mean that some Th-breeder concepts (see below) might be in trouble.

D. W. Magnuson and R. Gwin, reporting on some even newer experiments at ORNL, gave the designers reason to believe that they have been using the right number after all. Two independent measurements at ORNL came up with the values 2.31 ± 0.06 and 2.268 ± 0.042.

The long-range result has been the attention drawn to the unsatisfactory state of the world's knowledge about the η's of the fissionable nuclides. (Reactor design is probably more sensitive to η than to any other nuclear constant.) At the Detroit meeting, Alvin Weinberg (ORNL) described the situation as an international disgrace and announced plans in U. S. national labs to measure η for U^{233}, U^{235} and Pu^{239} to within 1%.

Th Breeder Looks Good. Babcock & Wilcox announced that for the past 27 months it has been studying the Th-U^{233} fuel cycle in pressurized-water reactors (NU, Sept. '58, 105). As a result, B & W is convinced that a thorium thermal-breeder reactor, using a variable mixture of light and heavy water as a coolant and moderator (NU, May '58, 80) can achieve breeding ratios as high as 1.10 for quite lengthy irradiation periods. A conceptual design presently under study uses fuel elements that are bundles of Zircaloy tubes containing a mixture of thorium and uranium oxides similar in geometry and size to those now being developed for the Consolidated Edison thorium reactor.



A general view of one of the isotope laboratories.

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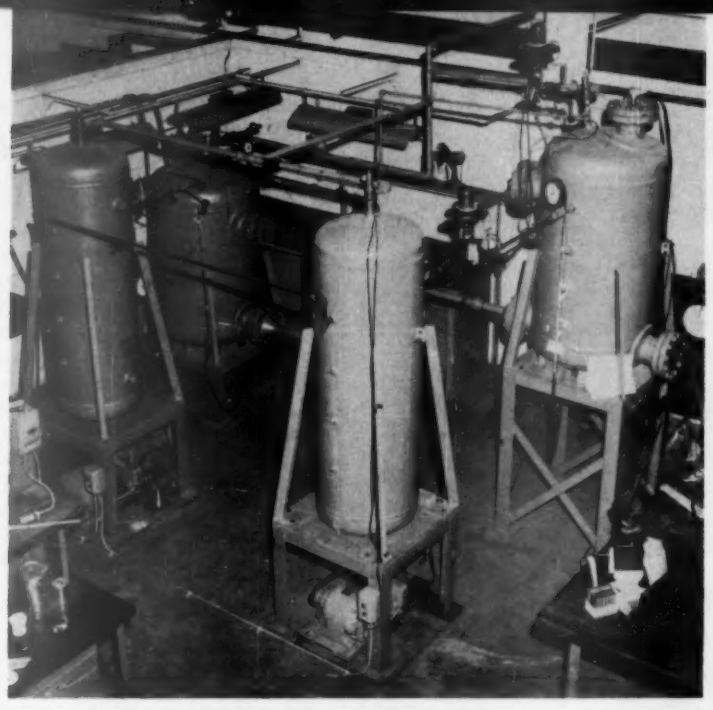

FIG. 1. Mockup of reflector-control system

Physical Simulation of a Variable-Reflector Reactor

By J. J. STONE, Jr., B. B. GORDON and R. S. BOYD
Battelle Memorial Institute, Columbus, Ohio

One method of controlling a boiling-water reactor is to use the steam pressure in the reactor pressure vessel to vary the height of the water reflector surrounding the core. As the steam pressure increases, the reflector height decreases. Thus, as the steam load varies, the reactor power level follows the load changes.

We initially studied such a control system using all-electronic simulation. This method required making assumptions concerning the magnitude of frictional forces in the hydraulic system. It was also necessary to assume that the inertial and frictional terms in equations of motion for the water in the reflector were determined primarily by the size of the connecting pipe. To determine the validity of these assumptions, a physical simulation (see Fig. 1) of the hydraulic portion of the reactor system was undertaken.

Reactor System

Figure 2 illustrates, diagrammatically, a reactor system controlled by the height of the water reflector. It represents a direct-cycle, natural-circulation, boiling-water reactor. The flow of steam upward through the core results in a circulation of water through ports in the annular reflector tank and down past the core along the inner surface of the pressure shell.

The annular reflector tank surrounding the core is partially filled with water. As the level of this water decreases, the reactivity decreases. Openings around the top of the reflector tank admit steam to the upper surface of the water in the reflector tank. The water in this annular tank connects, via a pipe, with an external surge tank in which a reference gas pressure is maintained. Any excess steam pressure in the reactor, over that required to maintain the water in the reflector system at equilibrium, will cause the following sequence: (a) flow of water to the surge tank, (b) decrease in reflector level, (c) decrease in reactivity,

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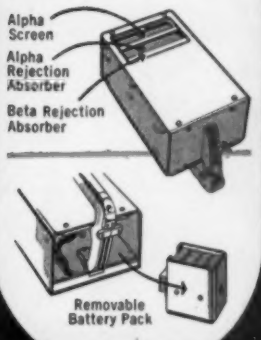

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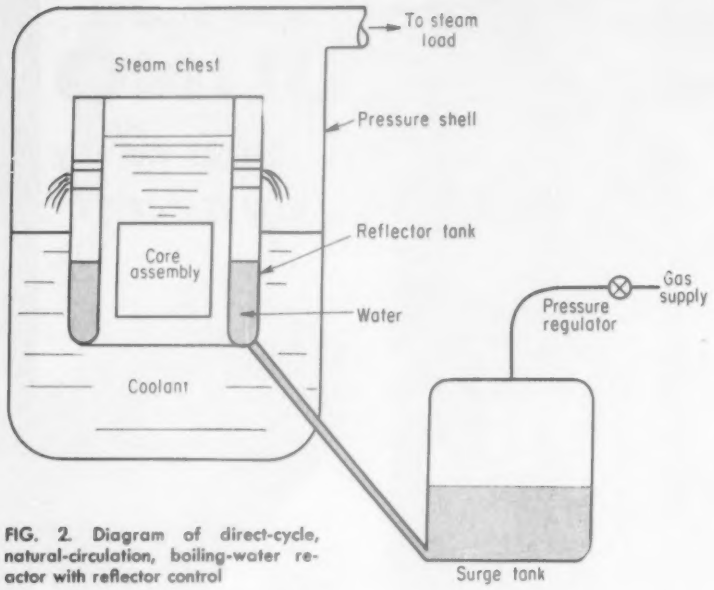


FIG. 2. Diagram of direct-cycle, natural-circulation, boiling-water reactor with reflector control

(d) tendency for a decrease in reactor power and (e) return of the steam pressure to its equilibrium value.

Hydraulic Simulator

A physical mock-up of this system was constructed. This hydraulic simulator consists of a reflector tank, surge tank and two pressure-accumulator tanks (to simulate the pressure shell).

The accumulator tanks are 16-ft³ pressure vessels mounted above, and connected to, a 3-hp air compressor. These tanks provide 500-psi air to the reflector and surge tanks. The surge tank (36-in. diameter) has provision for hydraulic coupling pipes (up to 6 in. in diameter) and various connecting ports for mechanical control valves and relief valves. An inlet-air-pressure regulator is used to reduce the 500-psi air from the accumulator tank to 300–302 psi in the surge tank. The outlet-air-pressure regulator is used to release air from the surge tank when the pressure there increases above 295 psi.

The reflector assembly consists of the reflector tank, two pneumatic control valves (with a controller) and a capacitance-type water-level indicator. In the reflector tank, which has a cross-sectional area of 5 ft², the water level can be raised 2 ft from the low portion without any interference from inlet air or water connections. The ½-in. pneumatic control valves are used on the inlet and outlet lines to the reflector tank and are both controlled by the same pneumatic signal.

Electronic Simulator

An analog computer was used in the analysis and evaluation of the nuclear portion of the reactor system. The computer was used to solve the equations describing the reactor kinetics, reflector reactivity and steam pressure under various load conditions. A standard group of reactor kinetic equations was employed. The Battelle Analog Facility has a self-contained unit to solve these equations.

For the purpose of this evaluation, it was assumed that boiling begins when water reaches the saturation temperature and increases linearly in intensity with further increases in water temperature. The rate of change of water temperature was computed as the difference between power produced by the reactor and power used to convert water to steam. From these relationships, the rate of steam production was determined.

The rate of change of the weight of steam in the steam chest is proportional to the difference between the rate of steam production and the rate of steam used to satisfy power demand. The pressure in the steam chest was determined from the weight of steam and the volume of the steam chest. This volume varies inversely as the

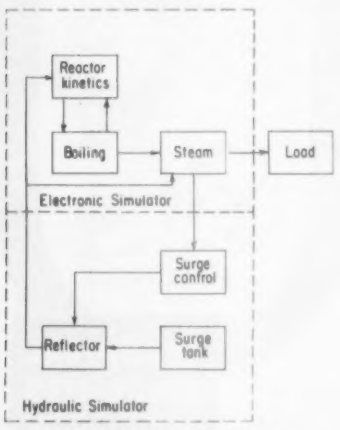


FIG. 3. Flow diagram of reflector-control system showing both hydraulic and electronic simulators

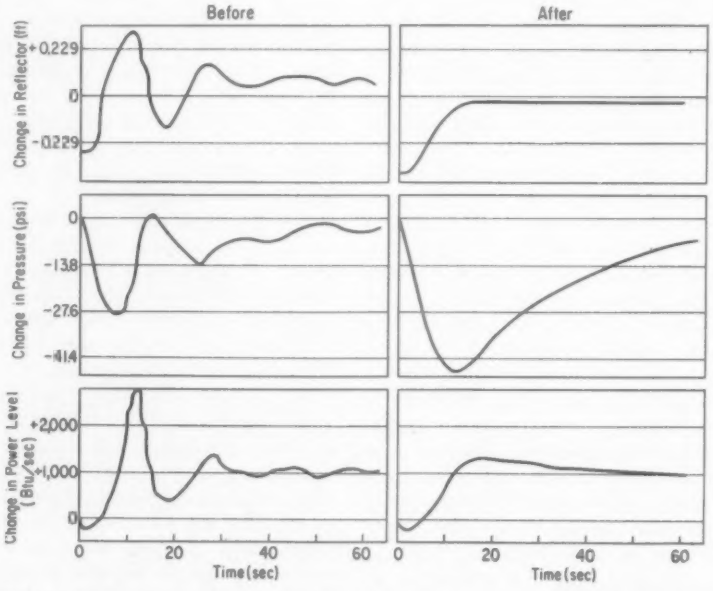


FIG. 4. Responses of system before and after insertion of five baffle plates in hydraulic coupling. Step change in power demand was 50–100%

height of the reflector; an increase in the volume of water in the reflector leaves less volume to be occupied by the steam. A voltage proportional to this computed pressure was fed to the hydraulic simulator.

Two main factors affect δk in this system: reflector worth, which is a function of reflector height, and steam-void fraction, which is a function of power level and pressure.

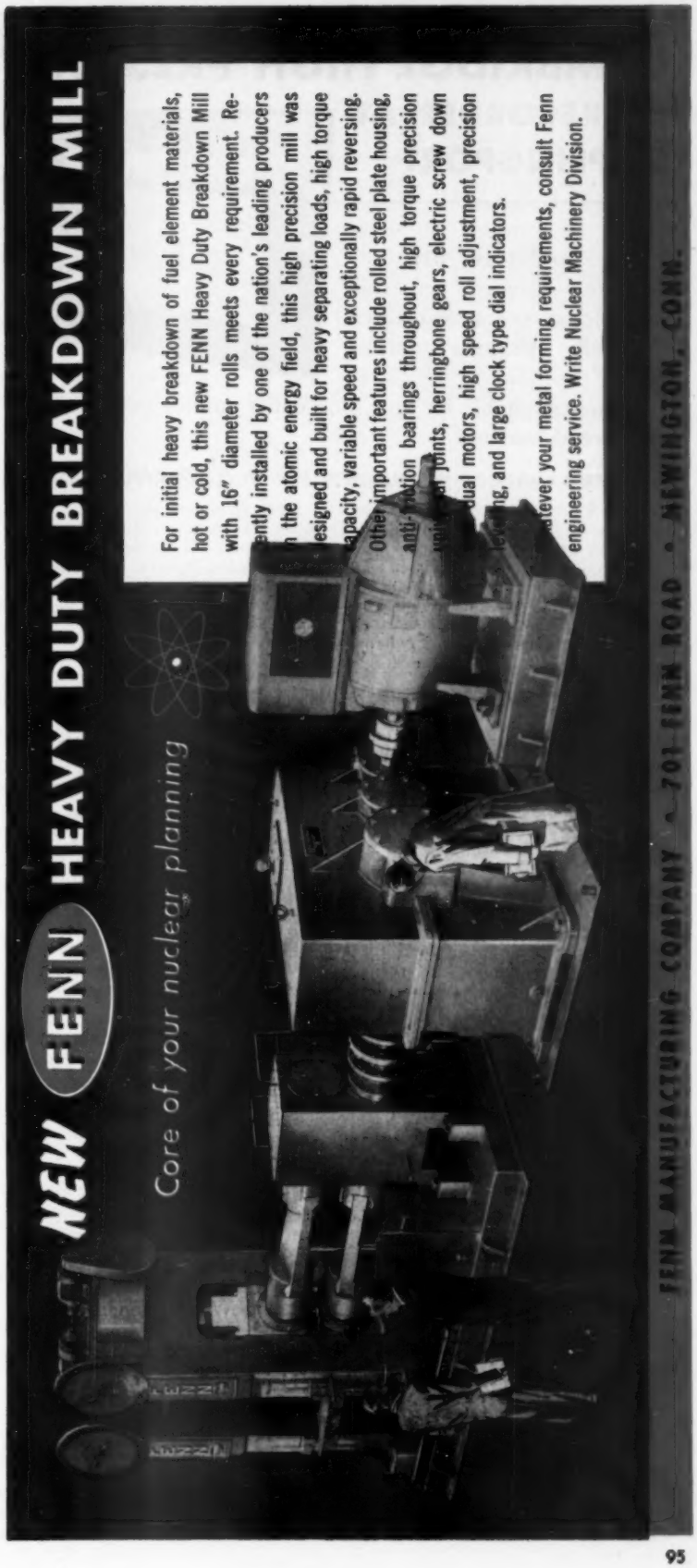
Simulated System

The electronic and hydraulic portions of the system were coupled together as shown schematically in Fig. 3 to simulate the entire reactor system. A pressure-demand signal from the computer was used to determine the set-point of the controller. The actual pressure in the simulated reflector tank was compared with the set-point pressure, and the error determined the pneumatic signal to the control valves. If the pressure in the reflector tank were lower than the demand pressure, the control valve to the accumulator would open to increase the pressure. Conversely, if the pressure in the reflector tank were too high, the control valve to the atmosphere would open to exhaust the pressure. The control valves were adjusted so that, at set-point pressure, both are slightly open.

The pressure controller used in this simulation employed proportional-plus-reset control. Both the proportional band and reset rate were set at their minimum values. In addition, because of an undesirable time lag between the pressure in the reflector tank and the demand pressure, an anticipation circuit was included. The output of this circuit was added to the pressure-demand signal to produce the controller set-point signal. This was, effectively, rate control. This circuit was adjusted for optimum response of the controller.

To complete the loop, a signal proportional to the height of the reflector had to be fed back to the computer. The water level was indicated by a capacitance-type height gage. The output of this instrument was sent to an electronic recorder. The signal from a precision potentiometer geared to the recorder drive mechanism was used as the height indication required in the electronic simulation.

To study this system, the simulated reactor is brought up to power manually. The power-demand signal is adjusted to design-point power. When the demand pressure to the simulated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WRITE TODAY TO: William Spangler, Manager—Professional Employment, Department N-2, The Martin Company, Baltimore 3, Maryland

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reflector reaches the operating level, the system is put on automatic control.

System Instability

The system thus far described tends to oscillate. Because of the inertia associated with the water flowing through the connecting pipe, the water level tends to overshoot. The excess difference in water levels produced between the tanks is analogous to compressing a spring. This "compressed spring" produces a force which causes water to flow in the opposite direction in the connecting pipe. To dampen this oscillating tendency, friction must be added to the system.

To establish the required frictional forces for stable operation, several modifications of the hydraulic coupling were attempted: concentrations of steel wool, four 2-in., 90-degree elbows, a 1-in. orifice in a 2-in. pipe and a system of baffle plates.

Stable operation was achieved with the baffle plates. The hydraulic coupling consists of a section of 3-in.-i.d. tubing 9 in. long. Inserts and spacers were placed in the tube to damp the flow of water. The inserts are made of 14-gage brass and have 16½-in.-diameter holes. Eighteen inserts can be placed in the coupling in various combinations of spacings. The optimum responses occurred with the use of five inserts. Figure 4 shows the response of power level, pressure and reflector height before and after the system was damped.

With the system stable, the effects of changing the void coefficient and the incremental moderator worth of the reactor system were studied. Both the results of these studies and more detailed descriptions of the hydraulic and electronic simulators are contained in the references listed in the bibliography.

* * *

This work was performed under AEC contract W-7405-eng-92.

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3. M. Treshow, A. R. Snider, D. H. Shaftman. Design study of a nuclear power plant for 100-kw(e) and 400-kw(h) at capacity, ANL-5452 (1955)
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REACTOR ROUNDTABLE

A discussion place for new reactor ideas

Boiler-Superheater Reactor

By T. P. HECKMAN
Chicago Operations Office, U. S. A.E.C., Lemont, Illinois

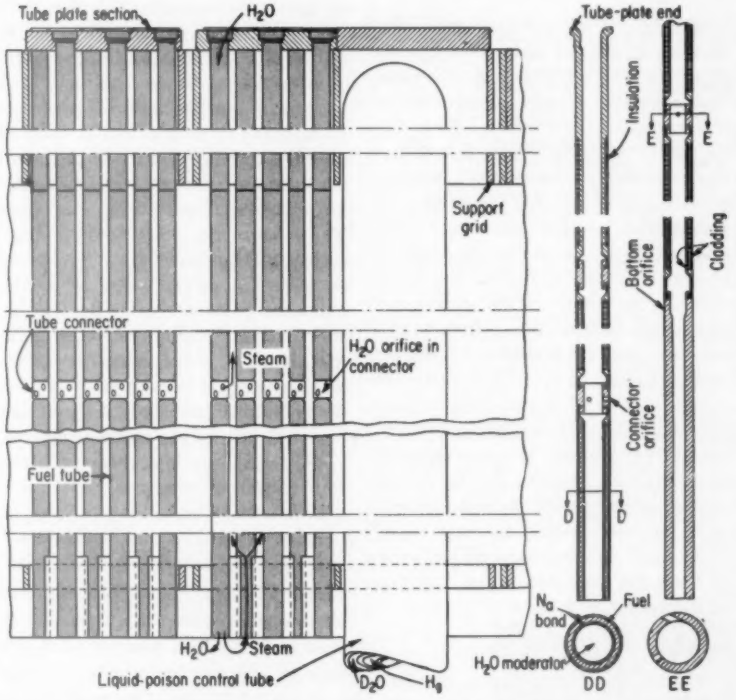
In the proposed reactor design heat is removed by both water and steam in independent coolant channels. Moderator-coolant water (see Fig. 1) flows down the center of tubular elements and out the bottom of the reactor; steam flows upward in the spaces between the elements where it is dried and superheated before exiting at the top of the reactor to the turbine. This arrangement increases the size of the core which makes for problems of mechanical design and fabrication and, in general, increases the reactor cost. In compensation the proposed design has these advantages compared with a conventional boiling-water reactor:

- Low rate of moderator recirculation will give savings in pumps, valves and piping.
- Dry or superheated steam provides economies in steam separators and in turbine design.
- Reactivity control is independent of the steam-void fraction; but control is directly related to the steam generation rate through the temperature coefficient.
- The design is insensitive to distortions of fuel-element dimensions induced by radiation damage or originally present.

Core Design

The reactor core is made up of a large number of vertical fuel-element tubes closely spaced on a triangular lattice. During normal operation, the H_2O moderator is contained only inside the tube and flows downward. Some of this moderator will pass through holes in the couplers in each tube train to wet the outside surface of the fuel-element tubes. Steam formed on the outside surface of the tubes plus the steam that separates from the H_2O at the bottom orifice of each tube will pass upward and out of the reactor. With moderator on the inside of the fuel elements only, the outside surface is available either to generate steam or to superheat steam.

The fuel is tubular in shape, but with intentional creases or grooves in the surface to diminish its structural strength. The fuel tube is then allowed to move mechanically within



SUPERHEATER AND ITS FUEL. Left—arrangement of tubular fuel elements in reactor core showing flow paths for steam and moderator-coolant water. Right—Fuel tube design detail. Insulation allows steam to be superheated at core exit FIG. 1

Roundtable Comments

TO THE REACTOR ROUNDTABLE EDITOR:

As Mr. Baron noted in describing his gaseous-fuel reactor (NU, Aug. '58, 128), the use of a gaseous fuel provides a number of advantages such as ease of control and reprocessing, unlimited burnup, and no fuel-element fabrication costs. However, only one gas, UF_6, appears to have sufficiently low boiling point and nuclear cross section to be considered, excluding organic compounds which probably have insufficient thermal and radiation stability. The practicality of using UF_6 as a reactor fuel depends primarily upon the rate of its decomposition and the degree of corrosion of system materials under reactor conditions of radiation and temperature. It would be very useful to obtain some data on this question by in-pile testing of heated, sealed capsules containing UF_6. The gaseous diffusion plants have successfully handled UF_6 for long periods, but this has been done with high nickel alloys, at relatively low temperatures, and not in a radiation field.

At Armour Research Foundation we are investigating a somewhat similar concept which seeks the achievement of the advantages of the gas-fuel reactor with reduced corrosion. Our fuel consists of fine particles of UO_2 or UC_2 entrained in a gas such as helium. By using BeO or graphite as moderator material, temperatures of 2,000°–3,000° F appear feasible in an all ceramic and gas core.

—D. KRUCOFF
Armour Research Foundation
Chicago, Illinois

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This article starts on page 97

the cladding tubes by using a liquid-metal heat-transfer bond. A fuel thickness of 0.045 in. and an H_2O diameter of 0.350 in. gives a moderator-to-fuel ratio of approximately 2.3.

The arrangement of fuel tubes suspended vertically from a top tube sheet (and possibly aligned at the bottom) can tolerate considerable mechanical deformation. Bowing of the tubes can affect the nuclear characteristics only slightly, and the heat-transfer characteristics to a minor degree since the steam flow pattern is changed by only a fraction of an inch. The moderator will always be present inside the tubes to prevent burnout, and the higher pressure inside the tubes as compared to outside the tubes will keep the tubes circular in cross section.

Cross sections of one fuel train with typical connectors are shown in Fig. 1. A full train will consist of a series of these shorter elements held together by crimping the ends into the connectors. Some of the connectors will also act as H_2O orifices, allowing H_2O to pass from the inside to the outside of the fuel-tube train. The individual fuel elements are simple enough in shape so that they could be mass-produced.

In addition to the fuel tube, the unit cell contains a space between the tubes for the counter flow of steam. For mechanical reasons, a large center-to-center spacing would facilitate the assembly, the structural support, and the unloading of the reactor. On the other hand, the larger this space the poorer the neutron economy. This first study chose a 0.75-in. center-to-center spacing of 0.5 in. o.d. tubes resulting in a ratio of 0.6 of the unit cell being steam area. Rough calculations for a 1,000-Mw(th) reactor indicate that an 11.5×11.5-ft core would be critical. However, several refinements in the mechanical design would improve the neutron economy considerably. One would be to increase the diameter of the end segments of a fuel-tube train. Another would be to vary the moderator-to-fuel ratio in both the axial and radial direction to flatten the neutron flux.

Heat Transfer

The recirculation pump maintains a differential pressure between the inside and outside of the fuel tubes. This ΔP intentionally suppresses the formation of steam in the moderator inside the fuel tubes.

Theoretically such a design could generate large quantities of saturated steam on a once-through basis. For practical reasons, the recirculation loop should be designed to handle a flow at least equal to, and probably greater than, the condensate return loop.

The vertical positions in the fuel-tube train at which connectors with orifices should be included can best be determined by mockup tests. Again, the ideal location and number would result in dry steam leaving the reactor and with no excess H_2O dropping from between the tubes to the lower pool. The study calculations indicated that two 0.02 in.-dia. holes in each of ten fuel-element connections, in each tube train, would do the job.

Any errors either in the design, the assembly, or the operation of these orifices can be compensated for by controlling the recirculation pump. This would also be true for excessive H_2O leakage through the top tube sheet since this excess falls by gravity to the lower plenum chamber to be pumped again to the upper plenum chamber.

The fission heat generated in the tubular fuel elements passes in both directions through the cladding tubes: to the H_2O moderator on the inside and to either an H_2O film or steam on the outside. The temperature of the cladding surfaces and the amount of heat passing in the two directions can be adjusted in several ways. The ΔP between the inside and the outside of the tubes is related to steam temperature for saturated steam conditions. The pressure inside the tubes is designed to suppress voids in the moderator and to force the proper amounts of H_2O through the connector orifices to wet the outside surface of the tubes. Should some of the connector orifices become plugged because of their small diameter, a larger part of the generated heat will flow to the inside moderator.

For maximum superheat, the H_2O would not be allowed to wet the outside surface of the fuel tubes until near the bottom end of the tubes. The inside cladding of the fuel element would be coated on either one or both sides with thermal insulation. An oxide of the tube material, or a ceramic coating, in contact with the Na heat-transfer surface would decrease appreciably the heat flow to the H_2O. With the uranium fuel generating heat at a safe

distance from the α-β transformation temperature, say 1,200° F, a superheat of 200° F at 600 psi could be accomplished.

Long exposure to irradiation will likely cause the tubes to bow, swell, or develop lumps as the present experience with natural uranium elements indicates. These mechanical deformations will result in several tubes making surface contact with one another, effecting, however, only local warm spots. Such mechanical defects would not change the moderator-to-fuel ratio, nor would the tubes be expected to collapse with the higher pressure inside the tubes. A mechanical misalignment of the tubes would distort the flow pattern of the outside water film and of the steam passage tending to cause a larger heat flow to the moderator but in only small localized areas.

Reactor Components

The reactor would be controlled by a method of positive displacement of Hg and D_2O through a system of concentric tubes. The scheme encloses a U tube within a U tube to guard against Hg leakage. The outer tube contains D_2O and the inner tube Hg; a pump and valve arrangement raises the D_2O column as the Hg column is lowered and vice versa. The reactor concept, however, is independent of this particular control scheme except for the calculations that indicate that 65 rods of 2.2 in. o.d. would be needed to properly control a loading to a $k_{eff} = 1.15$. Such a large Δk and large number of rods were selected in the hope of long periods of trouble-free operation.

The reactor core is reflected by H_2O on the sides and on both top and bottom. The bottom reflector can be varied in height from zero within the pressure vessel up to the bottom of the top reflector. With the bottom reflector raised to fill all of the steam spaces, the moderator-to-fuel ratio would be too great to allow the core to become critical, thereby serving as a shutdown safety device.

The i.d. of the pressure vessel would be ~15 feet for a 1,000 Mw(th) reactor. The design of a single closure for such a vessel that would be readily opened and closed is beyond present industrial capability. Therefore, a number of smaller openings together with a double valve side chute is proposed as the loading-unloading scheme. The fuel tubes would be handled in one assembly of several tubes at a time.

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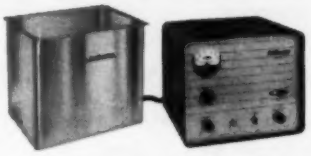

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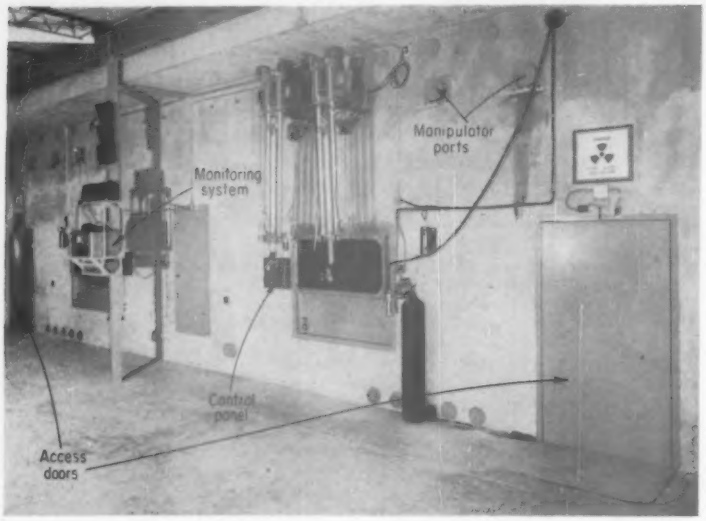
Tabulation of Power and Research

Name of reactor	Experimental Power Reactor Kahl†	Experimental High Temperature Power Reactor‡	Research Reactor Munich (FRM)	Research Reactor Frankfurt/Main (FRF)
Location	Kahl/Main	NRW Nuclear Research Establishment, Jülich	Garching near Munich	Frankfurt/Main
Principal for total installation	Rheinisch-Westfälisches Elektrizitätswerk AG. and Bayernwerk AG.	AVR, a group of Northrhine-Westphalian utilities	State of Bavaria, Technische Hochschule München§	State of Hessen, Johann Wolfgang-Goethe Univ. Frankfurt/Main
Reactor built for	same as principal	same as principal	Labor für Technische Physik der T.H. München	Institut für Kernphysik der Universität Frankfurt/Main**
Foreign contractor for reactor	General Electric Co., USA	none	AMF Atomics USA	Atomics International USA
German main contractor	Allgemeine Elektrizitäts-Gesellschaft AG., Frankfurt/Main	Nuclear Energy Group Brown, Boveri & Cie. AG., Mannheim Fried. Krupp, Essen	MAN (Maschinenfabrik Augsburg-Nürnberg)	
Type of reactor	Boiling water reactor	Pebble-bed reactor	Swimming-pool reactor	Water-boiler reactor
Nuclear fuel	2.6% enriched UO_2, 6400 kg; natural UO_2, 109 kg; zirconium-clad fuel elements, 88 assemblies	20% enriched uranium carbide, ~50 kg U 235, thorium carbide, ~1200 kg; graphite balls of 5 and 6 cm dia. resp.	20% enriched U, 4.28 kg (critical at 3.58 kg), BSR-type fuel elements, UAl_4 + Al-alloy	UO_2SO_4 dissolved in H_2O; 20% enriched, 1.8 kg (critical at 1.6 kg)
Moderator	H_2O	Graphite	H_2O	H_2O
Reflector	H_2O	Graphite	H_2O	Graphite
Power	60 Mw(th), 15 Mw(e)	48 Mw(th), 15 Mw(e)	1 Mw(th)	50 kw(th)
Neutron flux in center n/cm²/sec			thermal: 1.8×10^{13} max. fast: 5×10^{13} max.	thermal: about 10^{12} fast: about 2×10^{12}
Cooling:				
primary circuit	H_2O	Helium-neon mixture	H_2O in pool/heat exchanger	H_2O closed
reactor outlet temp., press.	285° C, 1,000 psi	600–1,000° C, 14.3–143 psia	32° C	
secondary circuit			H_2O from underground well, about 3,500 l/min.	H_2O closed
Control	21 control and safety rods	4 safety rods, controlled coolant flow	4 boron-carbide safety rods, 1 steel safety rod	4 boron-carbide rods
Shielding	concrete shielding of 2.70 m thickness		H_2O, lead, barite concrete, concrete	High-density concrete with borocalcite and magnetite added
Experimental facilities	—	—	6 beam channels, ϕ 15 cm; 1 beam chan., sq., 20 cm; 1 rabbit hole, ϕ 10 cm; 1 thermal column, 1.02 m² × 1.20 m; 1 gamma beam hole	5 horizontal channels, ϕ 7.5 and 10 cm; 4 vertical chans., ϕ 10 cm; 1 central chan., ϕ 4 cm; 2 rabbit holes, ϕ 4 and 5 cm; 1 vertical thermal column, ϕ 40 cm; 1 horizontal thermal col., 1.50 m² × 1.50 m; γ irradiation facility in subpile room

* Based on paper presented at World Power Conference sectional meeting, Montreal, Canada, Sept. 1958
† Presenty under construction; due to go critical in 1960, to full power in 1961
‡ Although designed, construction has not been started (see NU, Jan '59, 20); planned to go critical in 1961
¶ Corporation for the Application of Atomic Energy in Shipbuilding and Navigation
‖ Nuclear Reactor Construction and Operation Co.
§ Munich Institute of Technology
** Nuclear Physics Institute, Frankfurt Univ.
†† Hannover Institute of Technology
‡‡ Nuclear Physics Institute, Berlin

Reactors of West Germany*

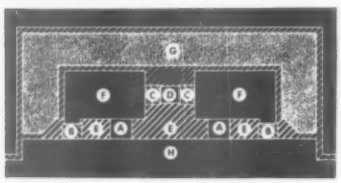
Research Reactor Hamburg (FRH)	Research Reactor Berlin (FRB)	MERLIN-type research reactor	DIDO-type testing reactor	Research Reactor Karlsruhe (FR 2)
Geesthacht near Hamburg	Wannsee near Berlin	NRW Atomic Energy Research Establishment, Jülich	NRW Atomic Energy Research Establishment, Jülich	Karlsruhe
Gesellschaft für Kernenergieverwertung in Schiffbau u. Schiffahrt mbH.,¶	Senate of the city of Berlin	State of North-Rhine-Westphalia	State of North-Rhine-Westphalia	Kernreaktor Bau-und Betriebs-Gesellschaft mbH‖
G.K.S.S., Hamburg and Kiel Universities, Technische Hochschule Hannover††	Institut für Kernphysik Berlin‡‡	Scientific colleges in the state: Cologne, Bonn, and Münster Univs., Aachen Technical College, Medical Acad., Düsseldorf	Scientific colleges in the state: Cologne, Bonn and Münster Univs., Aachen Technical College, Medical Acad., Düsseldorf	Kernreaktor Bau-und Betriebs-Gesellschaft mbH
Babcock & Wilcox Co. USA	Atomics International USA	AEI-John Thompson Nuclear Energy Co., UK	Head Wrightson Processes Ltd., UK	
Deutsche Babcock & Wilcox Dampfkessel-Werke AG.	Partnership: AEG, Borsig, Pintsch-Bamag, Siemens-Schuckert, direction: Pintsch-Bamag	Partnership: AEG-Rheinstahl	Partnership: AEG-Rheinstahl	
Swimming-pool reactor	Water-boiler reactor	Swimming-pool reactor	Heavy water reactor	Heavy water reactor
20% enriched U, 3.85 kg uranium-aluminium alloy MTR-type fuel elements	UO_2SO_4 dissolved in H_2O, 20% enriched, 1.8 kg	>90% enriched U, 6.9 kg, 49 MTR-type fuel elements, U + Al, Al can	>90% enriched U, 25 MTR-type fuel elements	Natural U, ~5 tons
H_2O	H_2O	H_2O	D_2O	D_2O
H_2O or graphite	Graphite	H_2O	D_2O, graphite	D_2O
5 Mw(th)		5 Mw(th) max.	10 Mw(th) max.	12 Mw
thermal: 3.2×10^{12} max. fast: 6.7×10^{12} max.	thermal: about 10^{12} fast: about 2×10^{12}	thermal: 5×10^{12}	thermal: 10^{14}	thermal: 3×10^{13} max. fast: 1.5×10^{13} max.
H_2O in pool/heat exchangers; 550 m³/hr 46° C H_2O heat exchanger/cooling tower, 440 m³/hr	H_2O closed ~30–80° C H_2O open	H_2O in pool with forced circulation; 3 m³/min. H_2O cooling towers	D_2O forced circulation H_2O cooling towers	D_2O closed 45° C H_2O
3 safety rods containing boron, 1 control rod	4 boron-carbide rods	2 safety rods; 1 shim rod; 1 regulating rod	Signal-arm shim safety rods	16 cadmium rods, ϕ 5 cm
H_2O, barite concrete, normal concrete, lead and iron and steel	High-density concrete, (S = 3.7 g/cm³m.Fe_3O_4 and $Ca_2B_6O_{11}$ added)	H_2O, lead, concrete	D_2O, lead, concrete steel	Boral, lead, iron and steel, concrete
7 radial beam channels, ϕ 15 cm; 4 tangential beam chans., ϕ 15 cm (every two opposed); 2 radial beam chans., ϕ 20 cm; 4 rabbit holes, ϕ 3.8 cm; 1 thermal column, 1.5 m × 1.5 m²; 1 window for irradiating large construction elements with mainly fast neutrons and beams, 1.7 m × 2 m²	Similar to FRF	(A) 1 central channel, ϕ 7.5 cm; 4 horizontal chans., ϕ 15 cm; 2 penetrating horizontal chans., ϕ 15 cm; 2 vertical chans., 7.5 × 15 cm; 1 shelf, 60 cm long; (B) 2 thermal columns, ϕ 1.35 m²; 1 horizontal chan., ϕ 30 cm; 3 horizontal chans., ϕ 15 cm; 1 vertical central chan., 7.5 × 7.5 × 60 cm	8 rigid, horizontal tubes through D_2O reflector; 10 do. in graphite reflector only; 1 rigid, horizontal, oval tube through D_2O reflector; 2 rigid, horizontal, rectangular tubes through graphite-bottom reflector; 18 removable, vertical tubes into D_2O reflector; 10 do., graphite reflector only; 10 thermal columns with square openings	13 horizontal channels in core; 12 chans. in graphite of thermal column; 43 vertical chans.; 1 vertical penetrating central chan.



OPERATING AREA has access doors at extreme right and left, monitoring system on post at center and viewing windows between post and doors. Control panels are beside viewing windows FIG. 1

Flexible Cobalt Facility Will Hold Up to 10^6 Curies

PLAN VIEW shows (A) viewing windows, (B) access doors, (C) shielding doors, (D) source-storage volume, (E) magnetite-concrete front wall, (F) irradiation cells and (G) earth-fill shielding FIG. 2



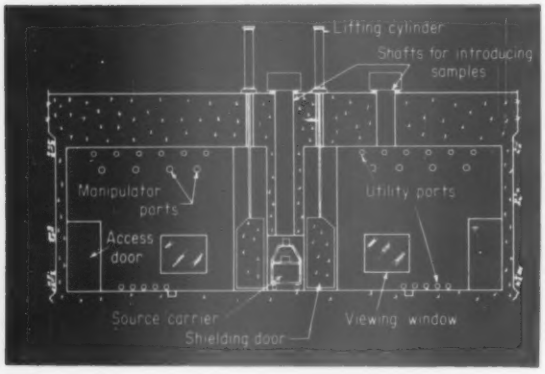
The irradiation facility at Southwest Research Institute was built under sponsorship of Pratt and Whitney Aircraft for use in testing lubricants. The design permits subjecting fluids to a combination of mechanical stress, high temperature, oxidative atmosphere and gamma radiation. Designers were E. A. Droegemueller and R. K. Nelson of Pratt and Whitney and J. M. Clark, Jr., of Southwest Research Institute.

Source. After consideration of accelerators, spent fuel and Co^{60}, the designers chose high-specific-activity Co^{60} for the radiation source. Computations showed that in view of self-absorption, small, high-specific-activity sources were preferable to larger sources of lower specific activity.

Cobalt disks are 1 cm in diameter and 2 mm thick. Four are enclosed in a stainless-steel "tape" $2\frac{1}{16}$ in. long and $\frac{1}{2}$ in. wide. Tapes are heliarc-welded at both ends and then mounted in the holders shown in Figs. 4 and 6. Source design was tested with a low-activity analog, in which Fe^{59} was used to represent Co^{60}.

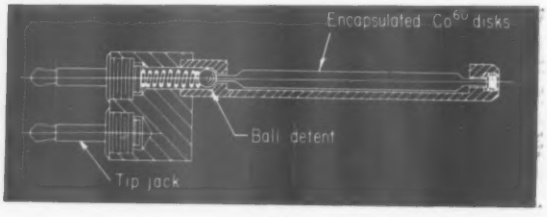
The present cobalt had an activity of 8,800 curies in January, 1957, but the facility is designed to handle up to 10^6 curies.

Cells. Static irradiations are conducted with the source in its storage volume. One or more experiments can be set up in each of the cells and ex-



VERTICAL CROSS SECTION shows storage volume at center, irradiation cells to left and right FIG. 3

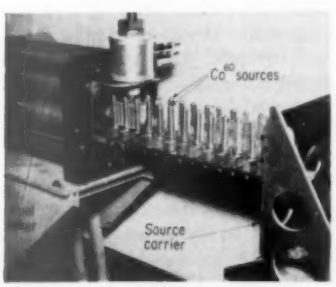
MOUNTINGS FOR Co^{60} hold 2-in. long stainless-steel "tapes," each containing 26 curies FIG. 4



IRRADIATION CELLS are 13 ft high, 9 × 15 ft in horizontal cross section. Source carrier rolls out of storage after experiment is in place FIG. 5

posed by rolling the source forward on one or both of the source carriers shown in Fig. 5. Model 8 manipulators will reach any part of both cells from four manipulator ports in each cell.

Shielding consists of ordinary concrete, magnetite concrete and earth as shown in Fig. 2. Shielding doors and access doors are of steel plate filled with 250-lb/ft³ iron-chip concrete. Hydraulic actuators raise and lower storage and access doors to open them. Viewing windows consist of a 3-in. slab of nonbrowning glass, 37 in. of zinc bromide solution, 2 in. of laminated plate glass. Thanks to the high index of refraction of the zinc bromide, the operator can see almost all points in the cell.



EXPERIMENT WITH FUEL COKER requires two rows of sources mounted so that source carrier can carry them into position on both sides of heated irradiation volume FIG. 6

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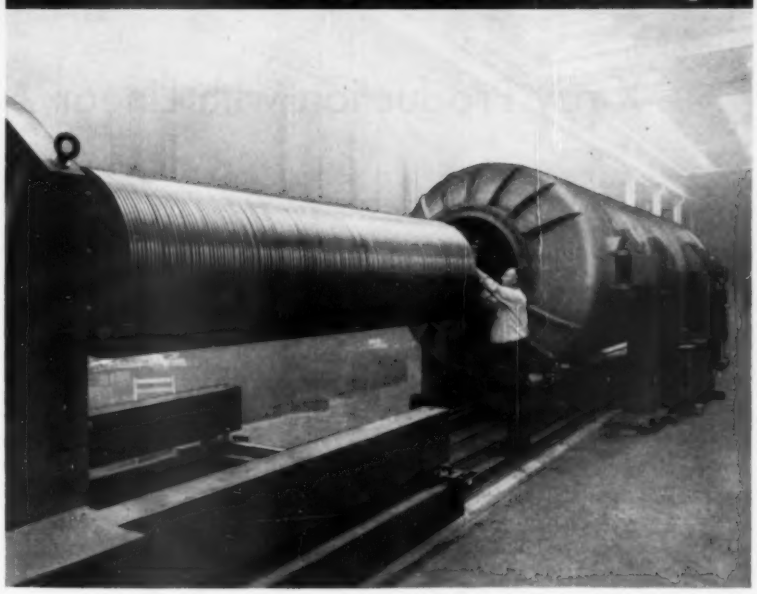

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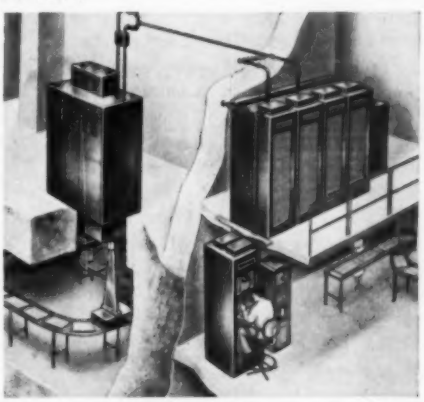

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X-ray Production with Linear Accelerators

By MALCOLM H. MacGREGOR
Applied Radiation Corp., Walnut Creek, California

Linear electron acclerators are particularly useful in their ability to produce intense bremsstrahlung beams. A knowledge of this photon production is important for both irradiation work and for shielding purposes when the electron beam is used directly. The graphs and table presented here are designed for evaluation of photon production and associated shielding problems.

Radiation lengths. If target thicknesses are expressed in radiation lengths, formulas for bremsstrahlung production are essentially the same for all elements. One radiation length is defined as the distance along the beam in which the energy of the typical electron is reduced to $1/e$ of its original value (*1*). Figure 1 gives radiation lengths as a function of atomic number.

Forward intensity. The most intense photon radiation occurs directly in line with the electron beam when a target of optimum thickness is placed in the beam. Figure 2 shows these maximum intensities (*2*). The forward intensity as a function of target thickness is shown in Fig. 3. The curve is for gold at 17 Mev (*3*), but it applies to all high-Z targets and all electron energies above 5 Mev (*4*). For low-Z targets and low electron energies, ionization losses become increasingly important (see Fig. 6), and the peak in Fig. 3 shifts somewhat toward smaller target thicknesses. Figures 2 and 3 together enable one to calculate forward photon intensity for a high-Z target and any combination of target thickness and electron energy over the range covered. For a low-Z target, forward intensity is lower. The effect of lower Z can be inserted by using Fig. 5.

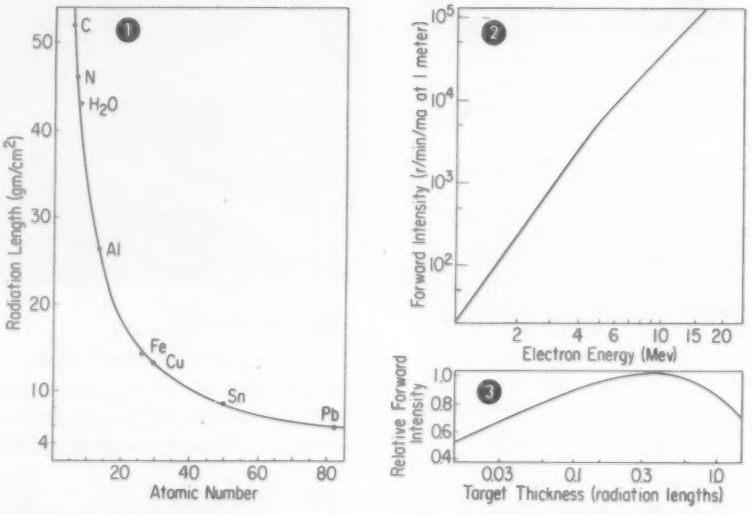
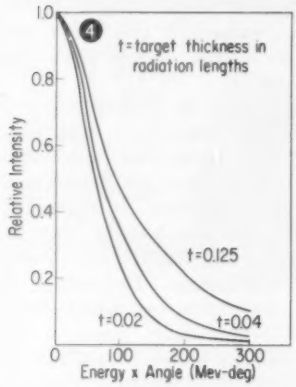


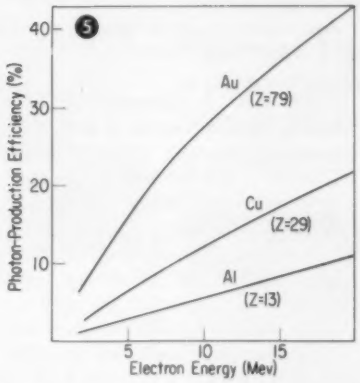
FIG. 1 shows radiation length as function of atomic number. Expressing target thickness in radiation lengths makes bremsstrahlung-production calculations essentially the same for all targets. FIG. 2 gives maximum photon intensity as a function of electron energy for a high-Z target of optimal thickness. FIG. 3 indicates variation of forward intensity with target thickness

Angular distribution. The curves of Fig. 4 enable calculation of intensities in other directions from the forward intensity. In the ranges covered these curves are in good agreement with experiment (*3*). There is an absence of data for energies above 5 Mev, particularly for thick targets. Shielding requirements are difficult to estimate. Probably a safe rule of thumb is that

Photons Produced per Unit Energy Range (relative)

Photon Energy	*Electron Energy (Mev)*					
(Mev)	*6.5*	*8.51*	*10.51*	*14.51*	*16.51*	*20.51*
2	45.3	130	208	418	550	868
4	10.6	50.1	86.2	183	245	396
6	..	22.8	46.6	108	147	241
8	..	1.73	25.2	71.4	99.1	167
10	..	..	2.10	49.1	71.4	123
12	..	..	..	31.0	52.0	95.5
14	..	..	..	2.84	34.1	75.5
16	..	..	..	..	3.22	58.8
18	..	..	..	..	..	40.6
20	..	..	..	..	..	3.97





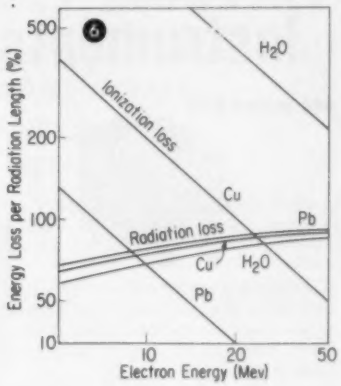
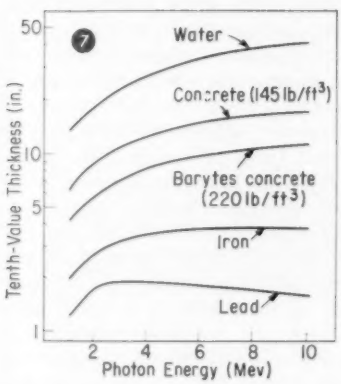
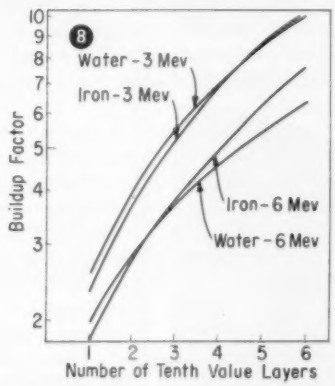


FIG. 4 tells beam width by plotting relative intensity against energy-angle product. FIG. 5 is total conversion efficiency for photon production from electron beam stopped in thick target.

FIG. 6 is thin-target conversion efficiency, given by $\epsilon = tk$, where t is target thickness and k is per cent of electron energy converted into photons per radiation length





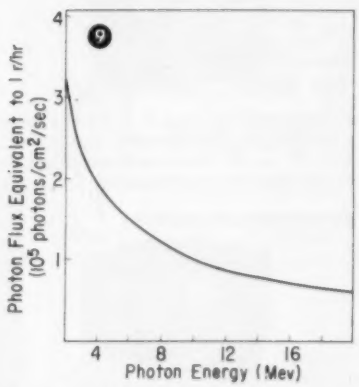


FIG. 7 gives thicknesses of various common shielding materials required to reduce narrow, monoenergetic photon beam to one tenth of its incident intensity. FIG. 8 shows buildup factors for use with FIG. 7 to find actual attenuation in broad-beam geometry. FIG. 9 shows equivalence of photon flux and dose rate to enable treatment of spectrum by energy intervals

for electron energies of 10–20 Mev and targets thicker than 0.2 radiation lengths photon intensity at 90 deg can be as high as 5% of forward intensity.

Total conversion efficiency. Figure 5 gives thick-target photon-production efficiencies (*4*). For thick targets conversion efficiency varies linearly with atomic number (*5*). Figure 6 enables computation of conversion efficiency from target thickness (*6*).

Spectrum shape. The number of photons in each energy interval of a bremsstrahlung spectrum is relatively independent of angle. The spectrum shape is shown by the table (*7*).

Shielding. The narrow-beam absorption coefficients of Fig. 7 (*8*) and the buildup factors of Fig. 8 (*9*) are for shielding calculations. For approximate calculations the spectrum of the table is replaced by an effective photon energy and Figs. 7 and 8 are used at that energy. For 20-Mev electrons the effective photon energy is ~7 Mev, and for 6-Mev electrons it is ~3 Mev. For more accurate treatment each component of the spectrum is treated separately. Figure 9 shows the equivalence between photon flux and dose rate in air. Figure 9, the table and Fig. 2 can be used together to obtain the forward flux at each energy. Figure 4 gives the flux in any other direction. The $1/r^2$ falloff and the shielding attenuation from Figs. 7 and 8 are then calculated for each energy group. Finally total dose rate is calculated from Fig. 9.

* * *

This data sheet is based on Report AM-100 (Applied Radiation Corp., Walnut Creek, Calif., March 13, 1957).

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BOOKS

The Practice of Nuclear Medicine

By W. H. BLAHD, F. K. BAUER and B. CASSEN (Charles C Thomas, Springfield, Ill., $12.50, xxiii + 407 pages, 1958).

Reviewed by EDITH H. QUIMBY, College of Physicians and Surgeons, New York, N. Y.

This book is addressed to "the clinician who is desirous of knowledge concerning the new field of nuclear medicine." It is therefore understandable that the sections on physics and instrumentation should be much briefer and less detailed than those on diagnosis and therapy. However, even from the point of view of the clinician, the section on physics seems too brief; the chapter on dosimetry is quite inadequate.

Instruments are discussed briefly in both the physics and laboratory sections. It is true that the clinician does not need to know a great deal about the theory of their operation, but several important things have either been barely mentioned or omitted entirely.

Treatment of counting statistics is cursory; there is no mention of resolving time of the counter or of possible losses at high counting rates. Autoradiography is dismissed with a single paragraph in the therapy section, which indicates that it is too difficult for most technicians and laboratories.

The present value of radioisotopes in a wide variety of diagnostic procedures is unquestioned, and in the near future new tests will doubtless be developed. The diagnostic section of this book consists for the most part of straightforward and well detailed accounts not only of the generally accepted procedures but also of experimental ones that show promise. Considered judgement is given of some that have not lived up to first expectations.

However, one chapter must be criticised. The radioiodine uptake test for study of thyroid function is probably the most widely used isotope diagnostic procedure at present. A carefully worked out set of instructions (such as is given for isotope dilution procedures) would have been valuable. Instead, directions for selecting the working distance are confusing and no mention is made of collimation. In the discussion of standardization, no attention is paid to the difference between the radiation reaching the counter from a sample in a beaker standing on the table, and that from a sample in the patient's thyroid, where scattered radiation from the neck, and absorption in tissues between the gland and the skin surface complicate the picture. Neglect of this factor can introduce large errors into the measurements.

The chapter on tumor-localizing procedures is conservative, describing methods but emphasizing their limitations. The section on gastro-intestinal and renal function, compartment volumes, and hematological diseases contains a great deal of practical and useful information. Techniques of sample preparation and measurement are set forth clearly. Some of the newer and less known procedures are included, with considerations as to their probable worth.

Isotope therapy offers less for the clinician than do the diagnostic procedures. The great hopes held out when isotopes first became widely available have not been realized. In the section on therapy considerable space is, of course, given to the use of radioactive iodine in treatment of several types of disease. The point is well made that there is a wide range of effective doses, and in procedures of clinical management, and that at the present time it is impossible to say which is best. Similar considerations hold for the treatment of hematologic diseases with radioactive phosphorus. In this section, however, one sentence cannot be allowed to pass unnoticed. It is stated that "one microcurie of radiophosphorus is equal, in terms of ionization, to 37 r of X-ray." This is completely meaningless, but it could be interpreted disastrously from the point of view of patient treatment.

The final chapter in this section is a purely descriptive account of the uses of sealed or solid sources in cancer therapy. It is prefaced by the statement that this is a therapeutic field in itself, and that the intention here is to summarize recent developments and evaluate the therapeutic value of these agents, the reader being referred to the bibliography for practical information. Unfortunately the bibliography is neither complete nor up to date.

The book is beautifully printed and profusely illustrated. There appears to be a suprisingly small number of misprints for a first printing.

In the field of nuclear medicine there are few worthwhile books. In spite of

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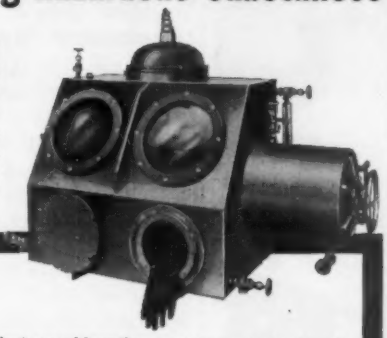

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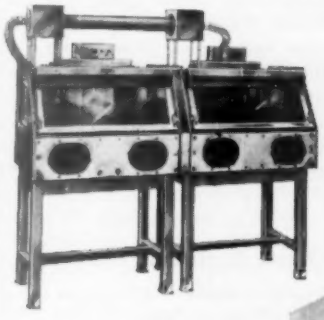

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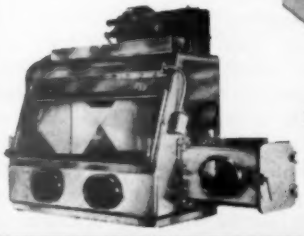

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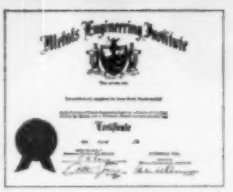

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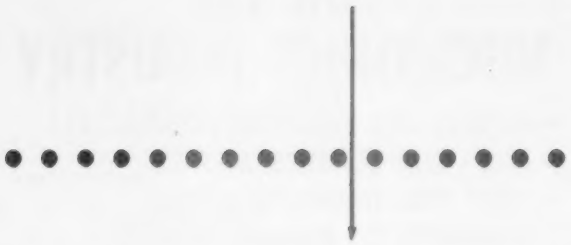

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Handbook of Physics

Edited by E. U. CONDON and HUGH ODISHAW (McGraw-Hill Book Co., New York, 1958, 1504 pages, $25.00).

For "Handbook" read "Handbuch," and for "Handbuch" read "Encyclopedia." This is the kind of handbook that has much text and few numbers. Thus it does not do again what the Chemical Rubber Co.'s "Handbook of Chemistry and Physics" does with its vast table of numbers, and it provides a lot more reading than one can find in the recent "American Institute of Physics Handbook". (NU, May '57, p. 126).

An impressive list of contributors have written sections on the following subjects: Mathematics, Mechanics of Particles and Rigid Bodies, Mechanics of Deformable Bodies, Electricity and Magnetism, Heat and Thermodynamics, Optics, Atomic Physics, Solid State, and Nuclear Physics. Physicists and engineers will welcome this as a volume to acquaint them with disciplines that are not their specialties and to remind them of things they have forgotten since classroom days.—RHE

Chronic Radiation Hazards

By G. J. NEARY, R. J. MUNSON and R. H. MOLE (Pergamon Press, New York, 1957, x + 191 pages, $7.50).

Reviewed by S. ALLAN LOUGH, Health and Safety Laboratory, New York Operations Office, U. S. Atomic Energy Commission, New York, N. Y.

This book is a delightfully detailed presentation and discussion of a large-scale chronic experiment on the effects of sustained exposure to ionizing radiation. The completeness with which the authors treat the material is gratifying and is reminiscent of earlier days when scientists found it easy more frequently to command large numbers of pages to present their experimental results. A young scientist interested in pursuing similar work would obtain real assistance in the planning stages of his efforts by making a careful study of the experimental descriptions contained herein. Team work between reactor operators and biologists over a period of nearly six

years during which the reactor's performance was adjusted to the needs of the biological experiment makes this investigation an unusual one.

This research report is presented in four sections: Experimental Design, Dosimetry, Results of Fast Neutron Irradiation and Relative Biological Efficiency of Fast Neutrons and Gamma Rays for Chronic Exposures. Each of the latter three sections is provided with an excellent summary. In addition there is a very helpful General Summary and Conclusions and a Glossary of Symbols at the end of the volume.

The section on Experimental Design includes a stepwise discussion of the ways in which the investigators arrived at the experimental conditions they finally employed.

The section on Dosimetry not only assures the reader that great care was exercised in estimation of dose rates to which animals were subjected but in addition is in itself an excellent discussion of the fundamental problems of the measurement of neutron and gamma radiation. The importance attached to this portion of the book is reflected by the 62 pages devoted to it.

Four similar colonies, each of 100 carefully selected mice, were exposed continuously to fast neutron doses of 0.08, 0.19, 0.54 and 6.4 rads/week, respectively. Contaminating gamma radiation was kept to less than 1 r/week except in the group receiving the highest neutron dose. The animals were unexposed to radiation during about 26 hr/week, but their environment was maintained constant by continuous residence in the irradiation tanks.

Among the conclusions reached by the authors after a wholesomely critical review of their data are the following:

1. Mean survival time was decreased by one-third at a fast-neutron dose of 6.4 rads/week.

2. The majority of the mice, both irradiated and controls, died without the cause of death being discovered post-mortem.

3. Mammary tumours and malignant tumours of the nasopharynx showed increased incidence at the high dose.

4. After about nine months at 6.4 rads weekly, there was an abrupt loss of weight.

5. White blood cell count did not predict radiation damage.

6. Gonadal damage was the earliest change detected and weight of the

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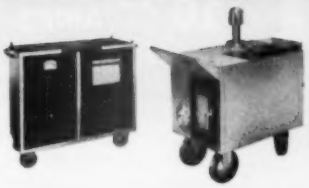

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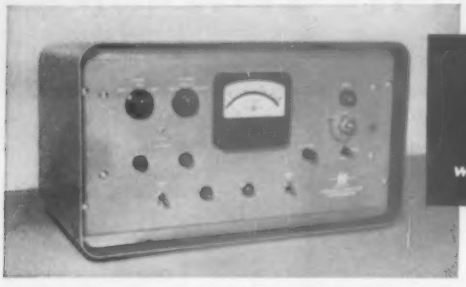

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BOOKS

Department starts on page 106

testes was a more sensitive indicator of radiation damage than fertility under the experimental conditions.

7. The life span was shortened by exposure to chronic irradiation limited to a few weeks or months; continued irradiation to death overestimated the amount required to shorten life span by a given amount.

The discussions of relative biological efficiency of fast neutrons is excellent. The data presented led the authors to the significant conclusion that "When a tissue is able to recover from radiation damage it may be wrong to calculate the r.b.e. for chronic irradiation from the total accumulated doses required to produce an effect. The proper comparison is between the dose rates which produce an effect of the same degree at the same time after the start of irradiation." Among other valuable observations the evidence indicated that the gonads are the organs that are the most sensitive to chronic irradiation at very low dose rates.

Anyone who wishes to engage in experiments on the biological effects of chronic irradiation can benefit materially by a careful study of this book.

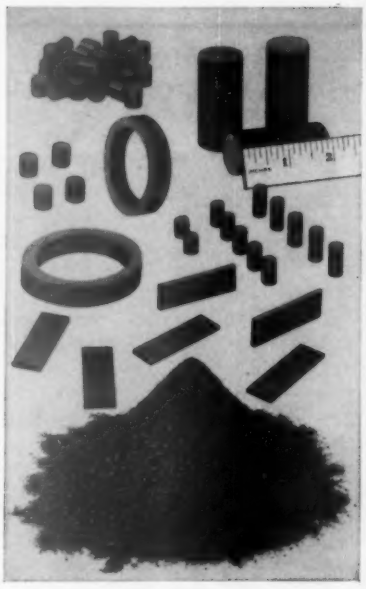
LETTERS

Hazard Warning

DEAR SIR:

Irradiation of polymeric hydrocarbons in contact with liquid nitrogen, which in turn is in contact with air, has resulted in detonations of sufficient force to merit the publication of a precautionary note to others in the field. Although no injuries have resulted, glass fragments from the shattered Dewar flasks have been projected with sufficient energies to jeopardize personnel in proximity to the occurrence.

Explosions have occurred during irradiation and during the interim between irradiation and the time at which the flasks and contents have returned to ambient temperature conditions. Cork, rubber and polyethylene have exhibited this phenomenon. Reactions have occurred as a series of



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small reports and more violently as a single shattering explosion. Disposition of the irradiated liquid nitrogen by evaporation into a hood in which volatile organic solvents were stored resulted in ignition of the vapors.

We attribute this phenomenon to the formation of ozone in irradiated oxygen, its condensation and solution in liquid nitrogen. Ozone (B.P., 161° K) is stable in liquid nitrogen and concentrates as irradiation continues and as nitrogen (B.P., 77° K) evaporates. When the nitrogen is completely gone, the temperature begins to rise. At the boiling point of liquid ozone there occurs a violent oxidation of any organic material present.

We have received word of a recent similar occurrence at the University of Michigan Fission Products Laboratory. We are hopeful that a word of caution will prevent the occurrence of accidents of a more serious nature and feel that NUCLEONICS might perform a service by publishing this information.

—L. B. BANGS, T. C. GREGSON and E. H. MANUEL
Research Division
The Goodyear Tire & Rubber Co.
Akron, Ohio

Corrections

DEAR SIR:

In my article "Effective Cross Sections for Thermal Spectra" (NU, October '58, 108), I wish to draw your attention to two printer's errors in the "box" on p. 109. In the last line in the 2nd paragraph of this box, "$T_0 = \frac{1}{2}mv_0^2$" should read "$kT_0 = \frac{1}{2}mv_0^2$." Eight lines lower, the text should read: " . . . $f = (T_0/T)^{3/2}[\sigma_{2,200}/\sigma(kT)]g$. Thus g is equal to f only at $T = T_0$, where . . . "

—C. H. WESTCOTT
Reactor Research and Development Division
Atomic Energy of Canada Ltd.
Chalk River, Ontario

What I Said Was . . .

DEAR SIR:

NUCLEONICS has misinterpreted my remarks on p. 27 of the December, 1958, issue to the effect that I said "no private reactor patents have ever been filed." What I actually said was ". . . there have been no private patents in reactors *issued* in this country."

—R. T. BRYAN
The Babcock & Wilcox Co.
New York, N. Y.

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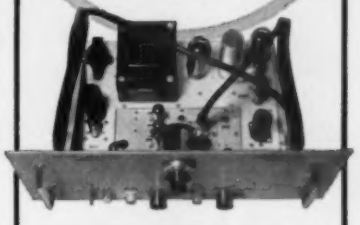

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Activation-Analysis Service

Activation-analysis service that can determine presence of one part per billion of boron in silicon permits quality control in manufacture and processing of chemicals, drug supplies, catalysts, metals, metal products, alloys and other materials in which control of trace elements is necessary.—Nuclear Science and Engineering Corp., P. O. Box 10901, Pittsburgh 36, Pa.

End-Window G-M Tubes

Range of alpha-beta-gamma end-window Geiger-Mueller tubes of varying window thicknesses includes detectors with bismuth-mesh cathodes that provide high sensitivity to gamma radiation, especially to low-energy I^{121} gamma rays. Quench filling prevents tube damage caused by temporary overvoltage and gives stable, reproducible operating characteristics.—Nucleonic Corp. of America, 196 Degraw St., Brooklyn 31, N. Y.

Engineering Test Loop

1,000-psia, forced-circulation-water test loop to be used in study of reactor heat transfer, fluid flow and corrosion over range of heat flux from 50,000 to 500,000 Btu/hr/ft² is available. Heat-flux values similar to those found in reactors are achieved by electrically heating various test specimens.—Nuclear Products-ERCO Div., ACF Industries, Inc., Washington 11, D. C.

Photomultiplier Tube

Model RCA-7265 14-stage head-on-type photomultiplier tube features improved photocathode. Spectral response covers range 3,000–7,500 Å, with maximum response at ~4,200 Å. Other features include electrostatically focused dynode stages, pulse-height resolution of about 8% and focusing and accelerating electrodes having external connections. Tube has flat faceplate, minimum photocathode diameter of 1.68 in. and maximum length of 7½ in.—Radio Corp. of America, Harrison, N. J.

High-Vacuum Pump

"Evapor-Ion" electronic pump operates with no outlet. Titanium wire, fed to post heated by electron bombardment from filament, evaporates and, upon striking cooled pump wall, condenses to thin layer. Nitrogen-gas molecules wander into pump from vacuum chamber and are ionized by electrons emitted by filament. Electrical field of accelerator grid violently repulses these ions and drives them into titanium layer, where they chemically combine with titanium. As each layer of titanium becomes chemically saturated, fresh layer is deposited. This constant removal of gas molecules by evaporation and ionization produces pressure in range of 10^{-4}–10^{-9} mm Hg. Nitrogen is pumped at speeds as high as 2,000 liters/sec.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Self-Lighted Markers

Markers require no electrical connections or external power source. Each unit is completely self-contained, comprised of glass tube internally coated with special phosphor and filled with tritium gas. Depending on end application and brightness requirements, these markers can provide uninterrupted light for up to 25 yr. Marker is readily visible at 100 ft or more, legible at 25–35 ft.—United States Radium Corp., Morristown, N. J.

Sample Applicator

Model 1260 sample applicator (above) has heated airstream for quick and accurate setup of paper chromatograms by pipetting. Largest size filter-paper sheets are held firmly by flexible metal fingers on either side of line of origin. Working area at line of origin is fully backlighted. Airstream temperature can be adjusted. Pipette bracket

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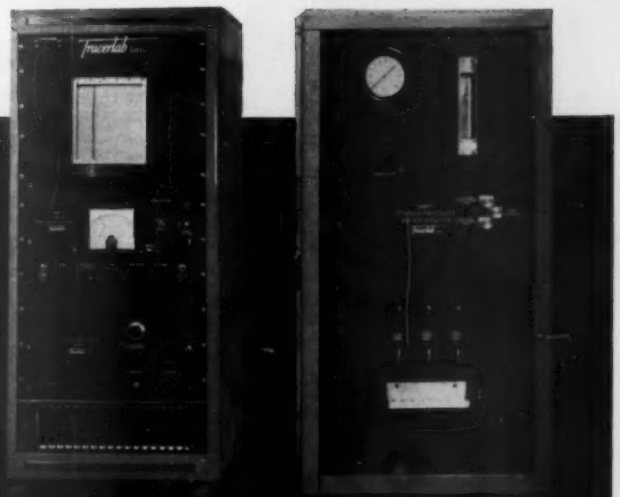

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PRODUCTS & MATERIALS

Department starts on page 112

pivots on moving carriage so that both vertical and horizontal positions of pipette in relation to paper are controlled.—Research Specialties Co., 2005 Hopkins St., Berkeley 7, Calif.

Well Counter

Model SC-1 well-type scintillation counter (above), designed to detect all levels of gamma radiation in prepared samples, is equipped with completely transistorized preamplifier. Lead shield of no less than 2½ in. in all directions reduces background counts to ~200 cpm under average conditions. Sensitivity is such that 10^{-5} μc of I^{131} can be detected with counting efficiency of ~50%, and 1 mc of I^{131} will give $>10^6$ cpm. Other features include counterbalanced lid with handles, removable plug over crystal to accommodate unusually long test tubes and samples up to 22 cm^3, and two-piece construction. Weight ~220 lbs.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Submicron Filter

Model MF-25 submicron filter for use primarily with distilled or demineralized water where it removes particulate matter down to 0.45 micron. Filter media is Millipore cellulose-ester membrane. Entire unit can be made of stainless steel or aluminum. Rate of flow is 25–100 gal/hr. Used in series with water still and demineralizer, the MF-25 helps produce ultra-pure water of 15,000,000-ohms resistance.—The Barnstead Still & Sterilizer Co., Lanesville Terrace, Boston 31, Mass.

Radioactive Gases

Gaseous mixtures are available with krypton-85, carbon-14, tritium or sulfur-35 compounds.—The Matheson Co., Inc., P. O. Box 85, East Rutherford, N. J.

Gamma-Beta Monitor

Model DZ14 bench-type detector provides warning and environmental monitoring of beta and gamma radiation. "Detectolab" incorporates positive "go-no-go" buzzer and lamp indications. Built-in time-delay circuit is incorporated to prevent false alarms. G-M tube plugs directly into rear of chassis. Unit operates from standard 110-v a-c outlet with built-in, self-con-

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This gamma-radiation alarm system has been especially designed to meet the new requirements of Section 70.24, Part 70, Title 10, Code of Federal Regulations, as promulgated November 11, 1958. The system incorporates a sensing unit that instantaneously activates dual modulated horns in the event of a criticality incident. The horns generate a distinctive and very loud sound that overrides plant noises. The system also includes door warning lights to direct evacuating personnel away from the critical area. In addition, the system has an automatic self-testing feature with audible and visual failure signals that can be installed anywhere. The sensitivity of the system can be factory preset between the limits of 3 mr/hr and 60 mr/hr to meet the requirements of 10 C.F.R. §70.24. The alarm is set off whenever the preset level is reached or exceeded no matter how high or how fast the flux rises. The life of the radiation sensor is essentially unlimited by the number of counts. The sensor is guaranteed by the manufacturer for 5×10^{10} counts. Only two types of tubes are used in the entire system; these tubes have an estimated service life of about 5 yr.—Nuclear Materials and Equipment Corp., Apollo, Pennsylvania.

tained power supply. Sensitivity is adjustable to 50–1,000 cpm.—BJ Electronics Div., Borg-Warner Corp., 3300 Newport Blvd., Santa Ana, Calif.

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Ratemeter

Radiodigit is pocket-sized Geiger-Mueller-tube ratemeter with following features: fully transistorized, printed circuits, rechargeable or dry battery, two ranges of measurement, indications given by loud-speaker or digital readout.—Elomag SPRL, 2 Avenue Wellington, Brussels 18, Belgium.

Photomultiplier Tube

Model 6342-A photomultiplier tube, which supersedes Model 6342, features improved pulse-height resolution, reduced transit-time variation, higher cathode luminous sensitivity and higher current amplification. Design features include semitransparent photocathode on curved inner surface of face end of bulb, minimum photocathode diameter of 1.68 in., faceplate with flat external surface, 10 electrostatically focused multiplying (dynode) stages and focusing electrode with external connection. Model 6342-A has spectral response covering range from ~3,000 to 6,500 Å with maximum response in blue region at ~4,000 Å. When operated at 1,250 v, it has median luminous sensitivity of 14 amp/lumen and current amplification of 175,000.—Radio Corp. of America, Harrison, N. J.

High-Voltage D-C Supply

Model 120-5-1 is d-c power supply, rated 5 ma at 120 kv. Its ripple is <2% rms.—Del Electronics Corp., 521 Homestead Ave., Mount Vernon, N. Y.

Flexible Hose of Ti

Small metal hose is produced from 0.010-in.-thick titanium strip formed into flexible tube of interlocking type with i.d. of 0.050 in. and o.d. of 0.115 in.—Flexonics Corp., Maywood, Ill.

Wire-Rope Slings

Acco-Registered wire-rope sling has 4-leg, 1⅛-in.-diam wire rope and anchor shackle from 4-legged spreader-bar sling. Slings have rated capacity of over 39 tons with angle of lift of 30 deg. They have been proof-tested at factory to withstand twice safe working load, based on safety factor of 5:1.—American Chain & Cable Co., Inc., 929 Connecticut Ave., Bridgeport 2, Conn.

Weighing Apparatus

Semi-automatic, dial-controlled apparatus (above) is capable of weighing objects of up to 50 kg, providing sensitivity to 10 mg (or 1 part in 5,000,000 relative to capacity) and doing it in minutes—Voland & Sons, 32 Relyea Place, New Rochelle, N. Y.

Geiger Counter

Uranoscope is fully transistorized gamma-radiation indicator with printed circuit and choice of rechargeable or dry battery. Indications are given by loudspeaker and neon tube with graduated scale.—ELOMAG, SPRL, 2 Avenue Wellington, Brussels 18, Belgium.

Shielded "Long" Counter

Model NC-2 shielded "long" counter has BF_3 detector enclosed in 8-in.-diam, paraffin-filled cylinder that moderates fast neutrons and discriminates against thermal neutrons. Cylinder is located in 15-in. shield that attenuates fast neutrons from side. Shield, consisting of concentric cans of brass, paraffin and cadmium, is ~3 in. thick. Detection efficiency is essentially independent of neutron energy from 50 kev to about 5.0 Mev. Fast-neutron sensitivity is 560 cpm per nv for PoBe neutron flux. Ratio of front-to-side

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PRODUCTS & MATERIALS

Department starts on page 112

sensitivity is ~2:1 for 4.5-Mev neutrons.—Tullamore Electronics Laboratory, 6055 S. Ashland Ave., Chicago 36, Ill.

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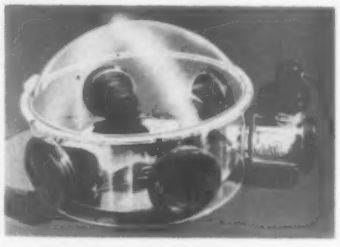
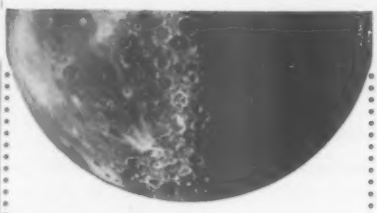
Lightweight honeycomb structures (above) of thin-walled ceramics made by Cercor process, can withstand temperatures up to 1,000° C (1,800° F) with virtually no thermal expansion and can operate continuously at 700° C (1,290° F). Coefficient of thermal expansion is 1×10^{-7}/° C (0–300° C). Available Cercor pieces have compressive strength, parallel to the channels, of 2,000 psi. Surface area of 20-hole/in. corrugated structures is 1,500 ft^2/ft^3. Material has density of about 30 lb/ft^3 and specific heat (room temperature) of 0.20. Average wall thickness is 0.005 in.—Corning Glass Works, Corning, N. Y.



Dry Box

Model 29 hemispherical dry box (above) is available in either all transparent plastic or in combinations of steel and plastic. Observation dome in both types is of plastic; circular tank is mild or stainless steel or plastic. The dry box can be evacuated by vacuum pump or purged by sodium-arc gas-purification system that burns up oxygen in box. "Lazy Susan" turntable is available in stainless steel. Standard diameter of dry box is 24 in. —Controlled Atmosphere Enclosures Mfg. Co., Inc., 1061 E. 8th St., Jacksonville 6, Fla.



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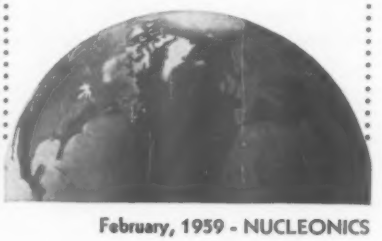


Radioactive Standards

Eight long-lived radioactive isotope standards, previously supplied by National Bureau of Standards, are available for immediate shipment. They include cesium-137; cobalt-60; radium D, E and F; iron-59; strontium-90; sulfur-35; tantalum-183 and thallium-204. All are solution standards, except radium, which is in plated form. These long-lived standards are additions to year-old line of short-lived standards: iodine-131, phosphorus-32, gold-98, sodium-24 and potassium-42. —Nuclear-Chicago Corp., 223 W. Erie St., Chicago 10, Ill.

LITERATURE AVAILABLE

Laboratory instruments are described in 24-p. Catalog M.—The Ealing Corp., 40 University Rd., Cambridge 38, Mass.

Chemicals, metals and minerals available are listed in 12-p. booklet.—Foote Mineral Co., 18 W. Chelten Ave., Philadelphia 44, Pa.

Recorders, controllers and indicators are described in 12-p. Bulletin GEA-6792.—General Electric Co., Schenectady 5, N. Y.

Manufactured-graphite technical data is contained in looseleaf handbook, registered copies of which will be available to selected technical people.—National Carbon Co. Div., Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y.

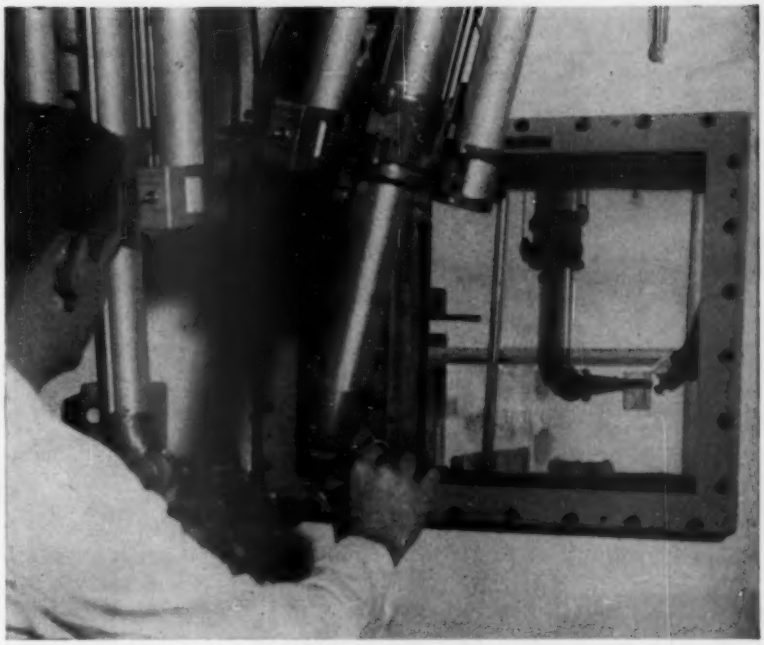
Electronic instruments are described in 4-p. short-form catalog. —Eldorado Electronics, 2821 Tenth St., Berkeley, Calif.

Zirconium-hydride properties and applications are given in 4-p. data sheet. —Metal Hydrides, Inc., Congress St., Beverly, Mass.

Ion-exchange technique is explained in 60-p. Bulletin Z-5.—National Aluminate Corp., 6318 W. 66th Pl., Chicago 38, Ill.

Ion-exchange resins are covered in 4-p. data sheet with price list.—BIO-RAD Laboratories, 32nd & Griffin Ave., Richmond, Calif.

"Crucibles for Metal Melting" is



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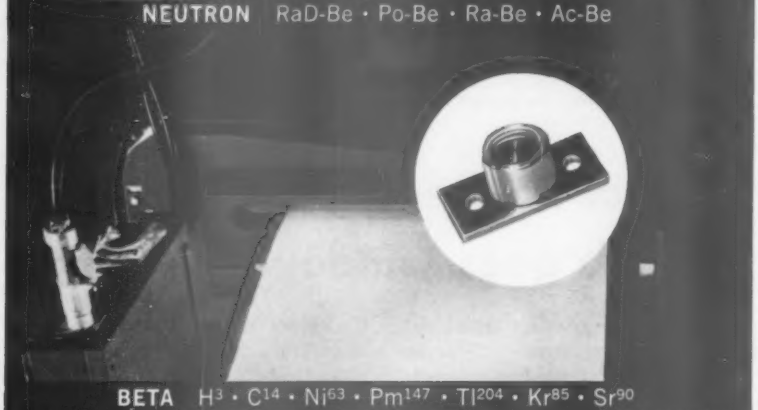

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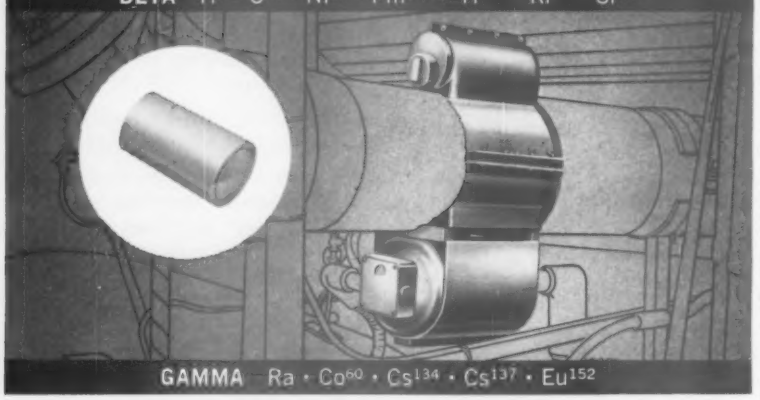

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PRODUCTS & MATERIALS

This article starts on page 112

title of 16-p. catalog.—Norton Co., Worcester 6, Mass.

Permanent magnet is described in data sheet.—Schlumberger Well Surveying Corp., Ridgefield, Conn.

Radioactive gases are listed in catalog. —The Matheson Co., Inc., P. O. Box 85, East Rutherford, N. J.

Indian Point nuclear power plant is discussed in 16-p. paper prepared for 1958 Geneva Conference.—Consolidated Edison Co. of New York, Inc., 4 Irving Pl., New York 3, N. Y.

Condenser-tube welding techniques are depicted in 9-min film (16 mm).—Allis-Chalmers Manufacturing Co., Milwaukee 1, Wisc.

Vibrating-reed modulator, low drift, is described in 4-p. Catalog 523.—Stevens-Arnold, Inc., 7 Elkins St., South Boston 27, Mass.

"Instrument News" is external house organ published periodically to further research, material analysis and production through electro-optical instrumentation.—The Perkin-Elmer Corp., Norwalk, Conn.

Beryllium-laboratory design is discussed in vol. 29, No. 469 of "Gazette." —Metropolitan-Vickers Electrical Co., Ltd., Trafford Park, Manchester 17, England.

Anion-exchange resin, liquid amine, nature and properties are discussed in 17-p. booklet.—Rohn & Haas Co., Washington Sq., Philadelphia 5, Pa. (also: Rohm & Haas Co. of Canada, Ltd., 2 Manse Rd., West Hill, Ontario).

Air-gage tracer lathe, remote controlled, designed for contouring radioactive materials is presented in 36-p. Booklet 2609.—The Monarch Machine Tool Co., Sidney, Ohio.

Ultrasonic equipment is described in 4-p. short-form catalog.—The Narda Ultrasonics Corp., 625 Main St., Westbury, N. Y.

Laboratory equipment is featured in "Apparatus Review," published periodically.—Arthur S. LaPine & Co., 6001 S. Knox Ave., Chicago 29, Ill.

Laboratory apparatus and chemicals are listed in "What's New for the Laboratory," published periodically.—Scientific Glass Apparatus Co., Inc., 100 Lakewood Terrace, Bloomfield, N. J.

Moisture determination in silica gel is detailed in 2-p. Report 4.58.—Schlumberger Well Surveying Corp., Ridgefield, Conn.

Rare metals, oxides and alloys are listed in three data sheets.—Shieldalloy Corp. Div., Metallurg, Inc., Newfield, N. J.

Pipe and tubing of rare and reactive metals are covered in 44-p. pamphlet.—Damascus Tube Co., Greenville, Pa.

Neutron activation analysis technique is discussed in Bulletin 94.—Tracerlab, Inc., 1601 Trapelo Rd., Waltham 54, Mass.

Radio-pharmaceuticals are given 18-p. price list.—Abbott Laboratories, 14th & Sheridan Rd., North Chicago, Ill.

Concrete-cutting lance is described in 4-p. folder.—Linde Co. Div., Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y.

Carbon-14 labeled compounds are given price list.—Research Specialties Co., 2005 Hopkins St., Berkeley 7, Calif.

Scaler, self-monitoring, is described in 2-p. Bulletin DS-1H.—Nuclear Measurements Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Plastic phosphor in new geometric forms is described in 2-p. Bulletin 16.—Nuclear Enterprises, Ltd., 1750 Pembina Hwy, Winnipeg 9, Canada.

Photomultiplier literature, including graphs of spectral sensitivity of semi-transparent photocathodes, is available.—EMI Electronics, Ltd., Ruislip, Middlesex, England (U. S. distributors: H. L. Hoffman & Co., Inc., 35 Old Country Rd., Westbury, N. Y.)

Engineering test loop is subject of 6-p. manual and 6 D-size drawings.—Nuclear Products-ERCO Div., ACF Industries, Inc., Washington 11, D. C.

Counting-rate meter is described in 2-p. Bulletin N-30.—Nucleonic Corp.

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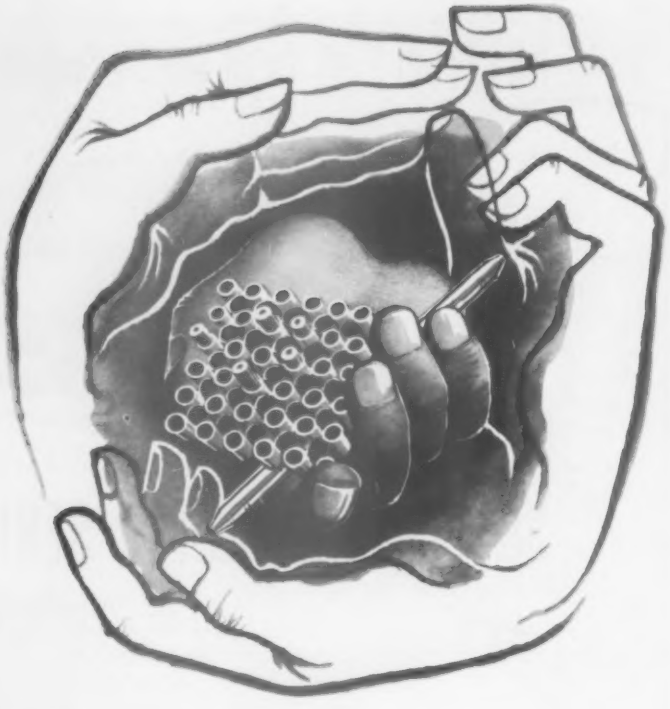

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Counting-rate meter is described in 2-p. Bulletin CRM-11—Nuclear Measurement Corp., 2460 N. Arlington Ave., Indianapolis 18, Ind.

Process chromatograph is discussed in 7-p. Bulletin 1836B.—Consolidated Electrodynamics Corp., 300 N. Sierra Madre Villa, Pasadena, Calif.

Air-filter paper is given price list.—Gelman Instrument Co., Chelsea, Mich.

Frequency-time standards are depicted in 4-p. brochure.—Ernst Norrman Laboratories, Williams Bay, Wisc.

Zinc-bromide window, copper lined, is described in 2-p. data sheet.—Research Equipment Co., P. O. Box 127, Glen Ellyn, Ill.

"Streamlines" is title of external house organ published periodically.—Henry Pratt Co., Inc., 2222 S. Halsted St., Chicago 8, Ill.

Nuclear safety service is offered in 6-p. foldout.—Byrne Associates, Inc., 50 Broadway, New York, N. Y.

Nuclear engineering activities and services are depicted in 12-p. brochure.—Stearns-Roger Mfg. Co., 660 Bannock St., Denver 17, Colo.

Coordinate comparator is described in 2-p. Bulletin 181-58.—Gaertner Scientific Corp., 1201 Wrightwood Ave., Chicago 14, Ill.

Research-laboratory facilities and achievements are depicted in 56-p. brochure.—Cook Electric Co., 2700 N. Southport Ave., Chicago 14, Ill.

Chromatography is subject of 4-p. bulletin.—Precision Scientific Co., 3737 W. Cortland, Chicago, Ill.

"Metal Specifications and Practices in the United States" is title of 15-p. booklet.—WaiMet Alloys Co., 1999 Guoin St., Detroit 7, Mich.

Closed-circuit television is described in 6-p. Bulletin GEA-6833.—General Electric Co., Schenectady 5, N. Y.

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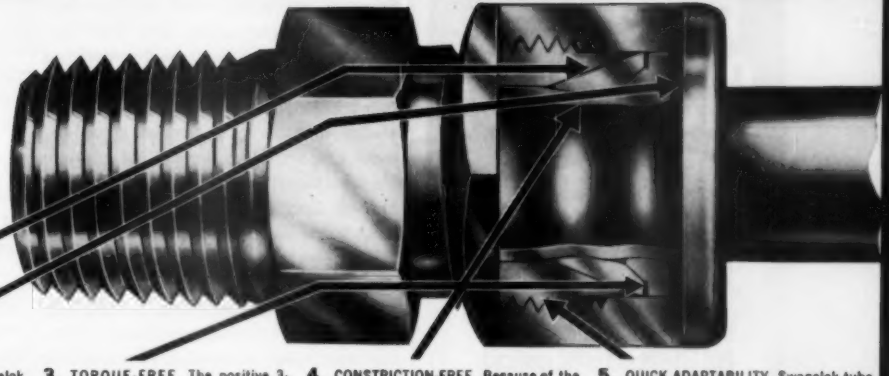

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INDUSTRY NOTES

• **Vard, Inc.,** Pasadena, Calif., is negotiating with two other southern California firms to form a new company with estimated annual sales of $20-million. The merger would combine Vard with **Royal Industries** (and its subsidiary, Royal Jet) and **Ideal-Aerosmith, Inc.**

• A substantial interest in **Atkins & Merrill, Inc.,** South Sudbury, Mass., has been acquired by **Roxbury Carpet Co.,** Saxonville, Mass. A & M makes models of nuclear reactors for testing and research.

• **Victoreen Instrument** has acquired **Tullamore Electronics,** Chicago, via an exchange of stock. Tullamore develops and manufactures nucleonics instruments, including analyzers, spectrometers and reactor controls.

• **Vitro Manufacturing Co.,** Pittsburgh, has resumed production of uranium-based colors for the ceramic industry (after an 18-year moratorium enforced by the government). AEC lifted the moratorium last June (NU, July '58, 22).

EXPANSIONS. Rolling mill facilities of **Brush Beryllium Co.** will be expanded at a cost of $250,000. . . . The Riverton, Wyo., uranium mill of **Fremont Minerals** went into production during December (500 tons/day U ore). . . . **High Voltage Engineering** is adding a 20,000 sq ft addition to its plant in Burlington, Mass.; to be completed in mid-year, the wing will be used in part for assembly of tandem Van de Graaff accelerators. . . . **Gene French Co.,** Albuquerque, has established a nuclear division to service the five nuclear firms it represents in the area. . . . **Kaman Aircraft,** Bloomfield, Conn., is building a lab-office complex in Colorado Springs, Colo., for its nuclear research division, which is now at Albuquerque, N. M.

NEW BUSINESS. The Air Force has given a $1.6-million contract to **Lockheed Aircraft's** Georgia plant for continuing work on nuclear-aircraft design. . . . Recent contracts in the Naval Reactor Program include: **1.** $600,000 to **Consolidated Controls Corp.,** Bethel, Conn., for design and manufacture of primary plant instrumentation for the first destroyer; and **2. General Electric's** small steam turbine dept. will supply four turbine-generator sets for the guided-missile frigate and two identical sets to the frigate's prototype reactor, under construction at West Milton, N. Y. . . . **Controls for Radiation,** Cambridge, Mass., is developing a tactical personnel dosimeter for the Army Chemical Corps; special automatic equipment is being designed to produce the dosimeters inexpensively in large quantities, according to Con-Rad. . . . **Nuclear Products-Erco** div. of ACF Industries has taken on a major nonnuclear job for the Air Force—maintenance of electronic flight simulators at various bases under a $903,000 contract; the company is closing its Buffalo plant. . . . All of the isolated-phase bus and low-voltage switchgear for Consolidated Edison's Indian Point, N. Y., reactor is being supplied by **I-T-E Circuit Breaker Co.,** Philadelphia. . . . **Allis-Chalmers** has given **Vard** a $60,000 contract to supply regulating and safety-rod drives for a pool-type reactor—Vard's first commercial contract for control-rod drives. . . . **Philips Electronics,** Mount Vernon, N. Y., has shipped its first four 100-kv X-ray spectrographs to GE, National Lead, Western Electric and Union Carbide Nuclear. . . . **Nuclear Science and Engineering,** Pittsburgh, is developing a radioactive assay method to be used by the Army Quartermaster Corps in its food-irradiation program. . . . **Catalytic Construction,** Philadelphia, is providing architect-engineering services for the cyclotron at Oak Ridge, which is to be completed by late 1960. . . . The European div., **Electronic Associates,** Brussels, has sold its third large analog computer—to the U. K. Atomic Energy Authority; the others went to Harwell and GE of England.

FINANCIAL. Record sales and earnings in 1958 have been reported by **Baird-Atomic,** Cambridge, Mass., and **Technical Operations,** Burlington Mass. For the fiscal year ended Sept. 30, Baird had sales of $6,744,800 (against $6,642,800 a year earlier) and earnings of 53 cents per share (against 8 cents in 1957); backlog was $2,350,000, reflecting a 40% increase in research and development contracts. Technical Operations reported sales of $2,363,000 and earnings of $96,300, the latter up 47% from 1957. . . . **Lithium Corp. of America** has declared a stock dividend of 4% for 1958, payable to holders of record Nov. 3.

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NUCLEAR CAMPUS

• The **roles of state and federal government** in protecting the public from radiation hazards will be the first phase of an atomic energy research project taken on by the **Univ. of Michigan.** Co-directors of the $160,000 project are Lee Hydeman and William Berman. The two will look into international health and safety aspects of the atom or third-party liability after the federal-state phase is completed.

• **Washington State College** is installing a liquid-metal heat transfer unit in the chemical engineering dept. for the study of heat extraction for nuclear reactors; it will use NaK.

• **Purdue Univ.'s** Duncan Laboratory of Nuclear Engineering has purchased a graphite exponential experimental facility from Cook Electric Co.

• **Rensselaer Polytechnic** has installed three vacuum-melting furnaces (with extensive control facilities) in the dept. of metallurgy; a forging press of 200 tons maximum force will round out a lab complex for melting and fabricating uranium, zirconium and other metals of nuclear interest. The equipment is being purchased with the help of grants of $54,000 from AEC and $8,500 from Consolidated Electrodynamics.

Courses

Theory and design of nuclear power reactors is being offered by Columbia Univ., beginning Feb. 4. **Advanced nuclear reactor theory** will be offered in the fall.

The 1959 curriculum at Oak Ridge Institute of Nuclear Studies includes **basic techniques of radioisotopes use** (for four weeks beginning Jan. 5, April 17, May 25, July 27 and Aug. 24), **industrial uses of isotopes** (for six weeks beginning Feb. 9 and Apr. 6) and a **special summer institute** for secondary-school science teachers (June 29–July 4). Further radioisotope courses will be scheduled as needed.

The ORINS Medical Division is offering seven courses during 1959.

A correspondence course in **atomic and nuclear physics** is being offered by the Univ. of California, Berkeley, in conjunction with the television series "Continental Classroom" (National Broadcasting Co.), beginning Feb. 11. Contact dept. of correspondence instruction, Univ. Extension, Berkeley 4.

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NEWSMAKERS

Three scientists listed in December "Newsmakers" as having joined the research staff of General Atomic's John Jay Hopkins Laboratory (NU, Dec. '58, 97), are on leaves of absence from their respective affiliations. They are: **Freeman J. Dyson,** Institute for Advanced Study, Princeton; **Robert R. Wilson,** Cornell; and **David H. Gurinsky,** Brookhaven National Laboratory.

A New York City attorney active in nuclear affairs, **Oscar Ruebhausen,** is acting as nuclear advisor to Gov. Nelson Rockefeller. Ruebhausen was a behind-the-scenes adviser to Rockefeller during his campaign.

R. Clyde Gerber, Jr., a senior engineer at Atomics International, has been named chief project engineer for the Hallam reactor to be built by AI for Consumers Public Power District, Nebraska. He succeeds **Robert L. Olson,** who has moved to a post in the general offices of AI's parent firm, North American Aviation.

Gerber

A ten-year veteran of Argonne National Laboratory's atomic energy program, **Roy Ringo,** has been appointed associate director of the physics div. Ringo joined the division in 1948 as an associate physicist, became a senior physicist in 1957 and, in his new post, will direct the division's work in experimental physics. He has specialized in experimental neutron physics.

Ringo

Col. John H. Rust has been named by Massachusetts Institute of Technology to direct an AEC-sponsored program to develop new and extended uses for radioisotopes in food. Rust retired Dec. 1 as chief, veterinary pathology section, Armed Forces Institute of Pathology.

Nelson J. Donahue has been promoted to chief of the reactor materials branch, technical and production div., AEC's Savannah River plant. He succeeds Paul J. Hagelson, deputy director of the division (NU, Jan. '58, 114).

Major personnel changes have been announced by Oak Ridge National Laboratory: **Walter H. Jordan** has moved up from director of the reactor projects division to assistant director of the Laboratory under Alvin M. Weinberg; Jordan has been succeeded as reactor projects chief by **Robert A. Charpie,** also an assistant director; **A. H. Snell,** another assistant director, has been named director of the ORNL Sherwood Project (marking formal establishment of an ORNL program to control the fusion reaction); **P. R. Bell** has been named co-director of ORNL's thermonuclear experimental division; and **E. D. Shipley** continues as a director of the division. Jordan will have four divisions and a panel reporting to him: the education, neutron physics, health physics, instrumentation and controls divisions and the mathematics panel. Charpie served as coordinator of the U. S. fusion exhibit at Geneva in September.

Jordan

Charpie

Snell

W. Kenneth Davis, former director of AEC's reactor development div., was awarded the 1958 Professional Progress Award of the American Institute of Chemical Engineers at its December meeting in Cincinnati. The Institute's nuclear engineering div. elected a new slate of officers for 1959: **John W. Clegg** (chairman), Battelle Institute; **Walton A. Rodger** (vice chairman), Argonne National Laboratory; and **Charles E. Dryden** (secretary-treasurer), Ohio State Univ. **O. L. Dwyer,** Brookhaven National Laboratories, was elected to a three-year term on the executive committee.

NUCLEAR CALENDAR

Feb. 25–26—Midwestern Symposium on Industrial Uses of Radioisotopes, Kansas State College, Manhattan. Sponsored by the college and AEC. Contact John Kitchens, Dept. of Continuing Education, KSC.

March 8–11—Gas Turbine Power Conference and Exhibit, American Society of Mechanical Engineers, Cincinnati (*Netherlands-Hilton*). Contact ASME, 29 W. 39th St., New York 18.

March 14–15—Fourth Annual Meeting of Southwestern Society of Nuclear Medicine, New Orleans (*Roosevelt*). Contact Samuel B. Nadler, 1520 Louisiana Ave., New Orleans 15.

March 16–20—11th Western Metal Congress and Exposition of American Society for Metals, Los Angeles (*Ambassador Hotel, Pan-Pacific Auditorium*). Technical session on nondestructive testing. Contact ASM, 7301 Euclid Ave., Cleveland 3, Ohio.

March 17–18—Conference on Air and Water Pollution Abatement, sponsored by Manufacturing Chemists' Assn., Cincinnati (*Netherlands Hilton*). Contact MCA, 1625 Eye St., N.W., Washington 6, D. C.

March 17–19—15th Annual Conference of National Assn. of Corrosion Engineers, Chicago (*Sherman*). Contact NACE, 1061 M & M Bldg., Houston 2, Tex.

March 23–26—National Convention of Institute of Radio Engineers, New York (*Waldorf-Astoria Hotel, New York Coliseum*). Contact IRE, 1 E. 79th St., New York 21.

Mar. 31–Apr. 1–2—21st American Power Conference, Chicago (*Sherman*). Contact R. A. Budenholzer, Mechanical Engineering Dept., Illinois Institute of Technology, 3300 Federal St., Chicago 16.

March 31–Apr. 2—Symposium on millimeter waves, sponsored by the Defense Dept.'s research agencies and the Institute of Radio Engineers, New York City (*Engineering Societies Bldg.*). Contact Jerome Fox, Brooklyn Polytechnic Institute, 55 Johnson St., Brooklyn.

April 5–10—5th Nuclear Congress and Atom Fair, Cleveland (*Public Auditorium*). Contact T. A. Marshall, Jr., Engineers Joint Council, 29 W. 39th St., New York 18.

Apr. 5–10—American Chemical Society's 135th national meeting, Boston (*several hotels*). Contact Otto H. York, Otto H. York Co., West Orange, N. J.

Apr. 16–30—Engineering, Marine, Welding and Nuclear Energy Exhibition, London (*Olympia London*). Emphasis on nuclear power. Contact F. W. Bridges & Sons, Ltd., Grand Buildings, Trafalgar Square, London W.C.2.

May 6–8—1959 Electronic Components Conference, sponsored by Institute of Radio Engineers, American Institute of Electrical Engineers, Electronic Industries Assoc. and West Coast Electronic Manufacturers Assoc., Philadelphia (*Benjamin Franklin*). Papers on instrumentation and control devices and radiation effects. Contact Bernard Osbahr, Electronic Industries, Chestnut & 56th Sts., Philadelphia 39.

May 30–June 5—5th World Petroleum Congress and Symposium on Applications of Atomic Energy to the Petroleum Industry, sponsored by the Permanent Council of the World Petroleum Congress, New York City. Contact C. E. Davis, gen. secy., 5th WPC, 527 Madison Ave., New York 22.

June 8–11—American Rocket Society semiannual meeting, San Diego. Session on nuclear propulsion. Contact Stan Gunn, Rocketdyne, 6633 Canoga Park Ave., Canoga Park, Calif.

June 14–18—Semiannual meeting American Society of Mechanical Engineers, St. Louis (*Chase-Park Plaza Hotels*).

June 15–17—Annual meeting of the American Nuclear Society, Gatlinburg, Tenn. Contact Octave J. DuTemple, John Crerar Library, 86 E. Randolph St., Chicago 1.

June 18–20—Fourth Annual Meeting of Health Physics Society, Gatlinburg, Tenn. Contact G. T. Saunders, Kewaunee Mfg. Co., Adrian, Mich.

June 18–20—Society of Nuclear Medicine, Chicago (*Palmer House*).

June 24–26—2nd Nuclear Instrumentation Symposium, Idaho Falls, Idaho. Contact H. S. Kindler, Instrument Society of America, 313 Sixth Ave., Pittsburgh 22, Pa.

July 23–30—9th International Congress of Radiology, Munich, Germany. Contact Sekretariat des 9, Internationalen Kongresses fur Radiologie, Reitmorstrasse 29, Munich 22.

Sept. 21–25—International Conference on High Energy Accelerators and Their Instrumentation. Contact CERN Conference Secretariat, Geneva 23, Switz.

Sept. 28–Oct. 1—National Power Conference, cosponsored by American Society of Mechanical Engineers and American Institute of Electrical Engineers, Kansas City (*Muehlebach*). Contact ASME or AIEE, 33 W. 39th St., N. Y., N. Y.

Nov. 4–6—National Automatic Control Conference, sponsored by Institute of Radio Engineers, Dallas (*Sheraton*). Also participating: American Institute of Electrical Engineers and Instrument Society of America. Contact G. S. Axelby, Westinghouse, Box 746, Baltimore 3, Md.

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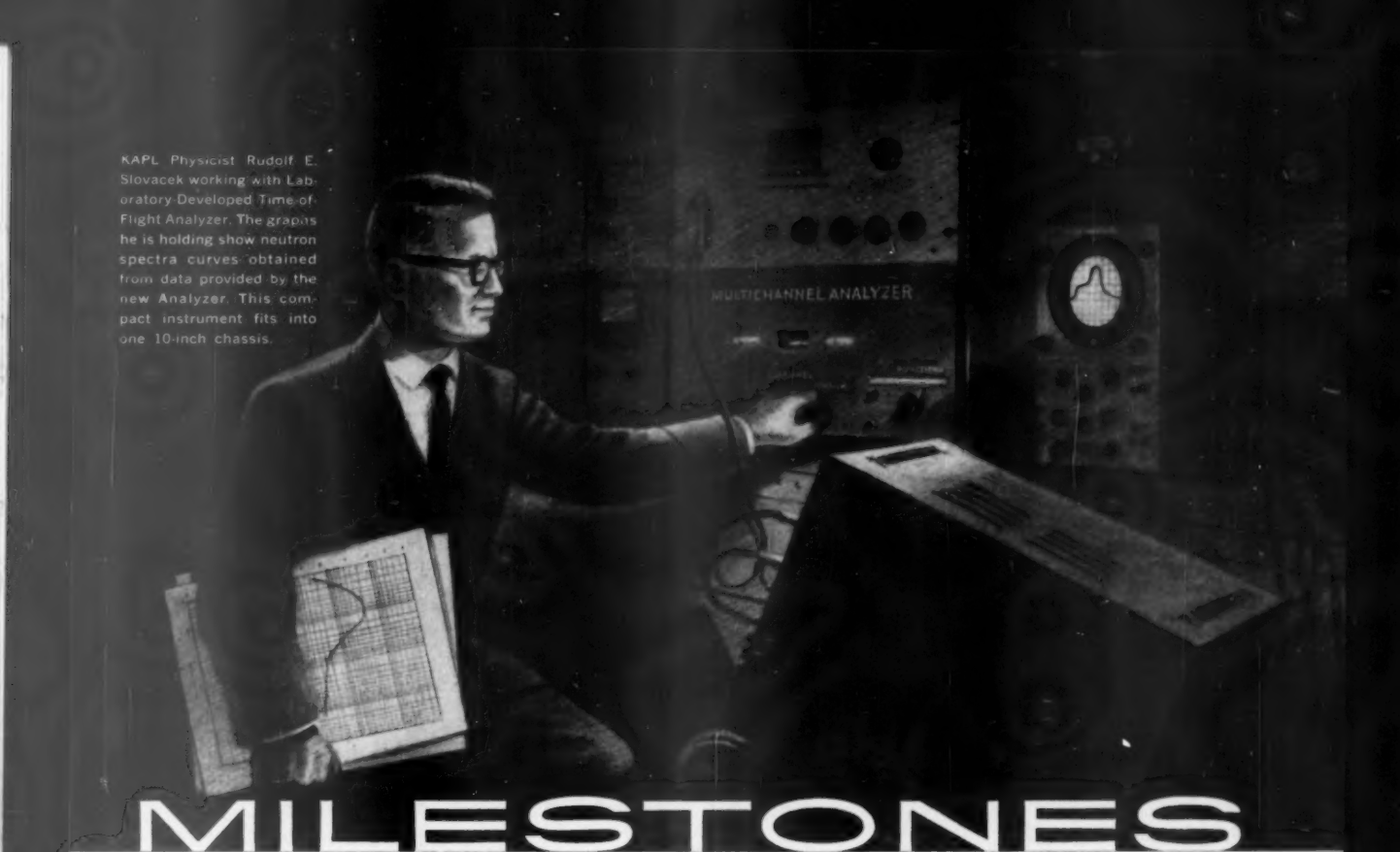

KAPL Physicist Rudolf E. Slovacek working with Laboratory-Developed Time-of-Flight Analyzer. The graphs he is holding show neutron spectra curves obtained from data provided by the new Analyzer. This compact instrument fits into one 10-inch chassis.

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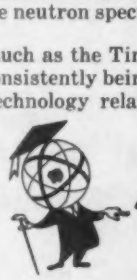
Rudolf E. Slovacek is one of a number of KAPL scientists concerned with reactor physics. He earned a BSEE at Union College in 1945, joined KAPL in 1951 after taking his MS in Physics at Indiana University. Since then he has contributed to several KAPL projects.



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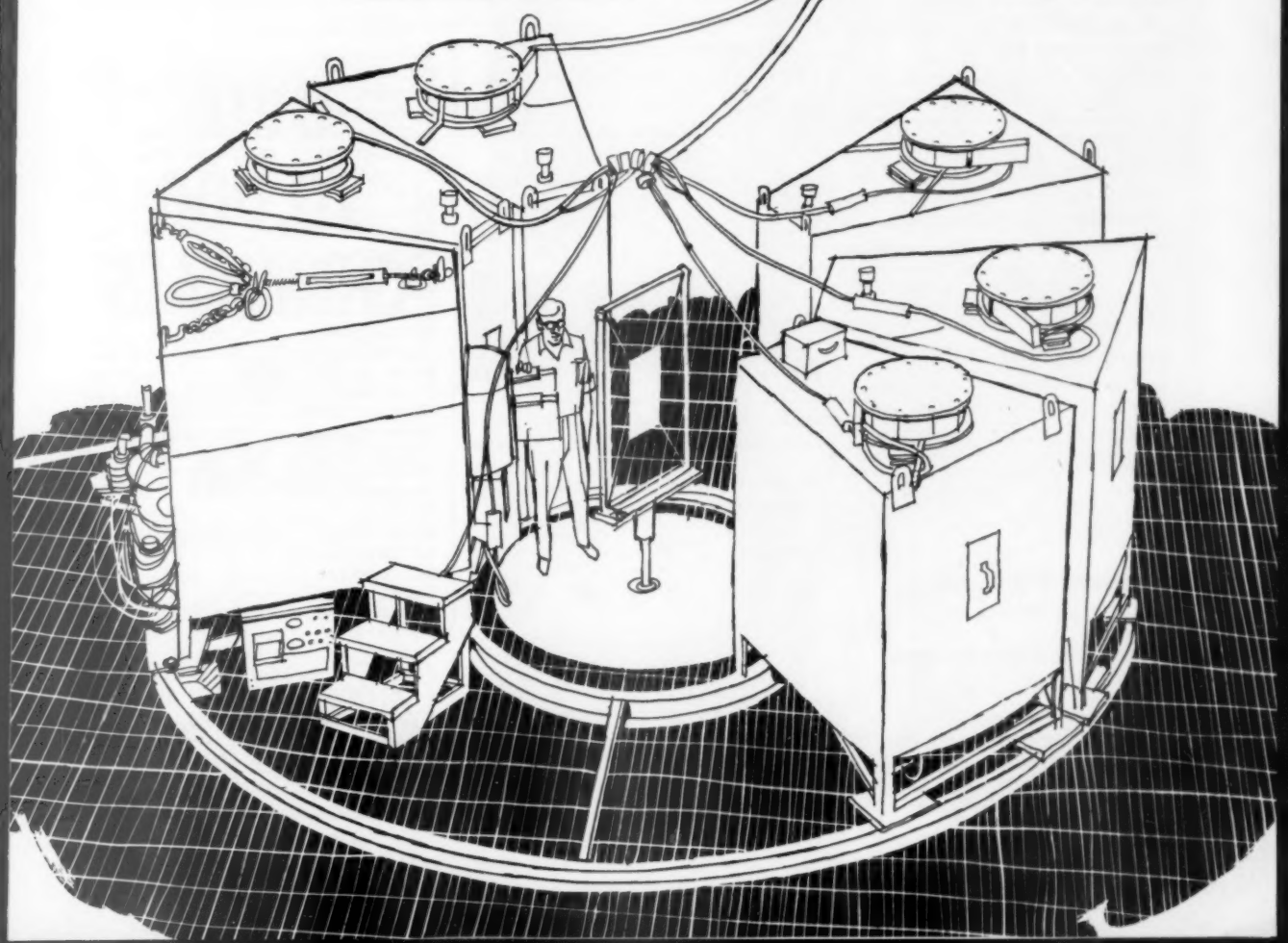

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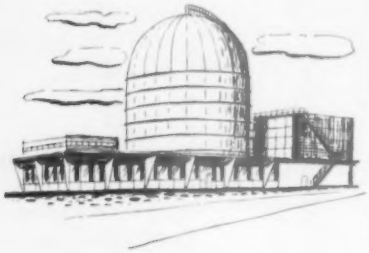

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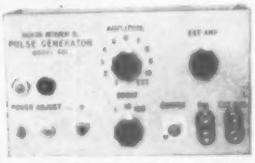

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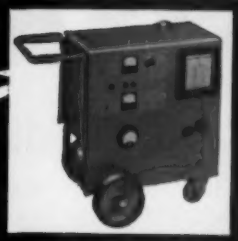

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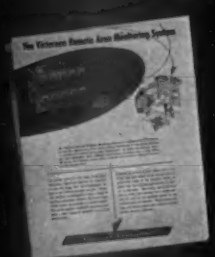

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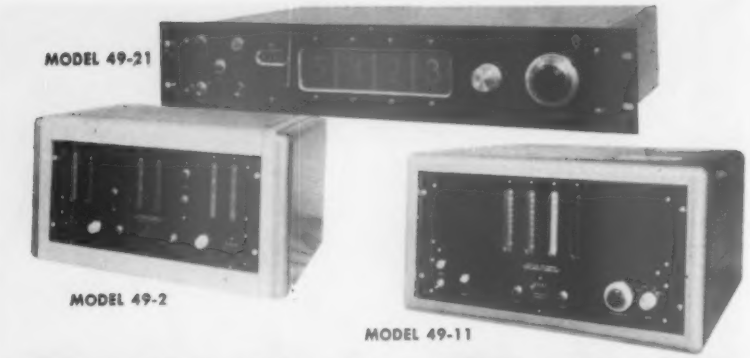

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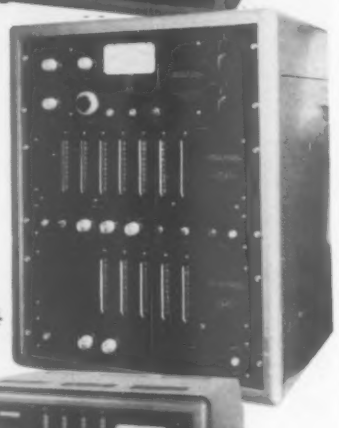
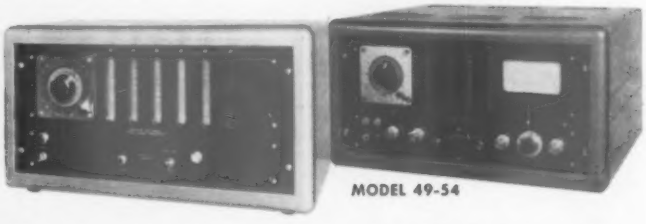
These are just some of the features available in RIDL Scalers.





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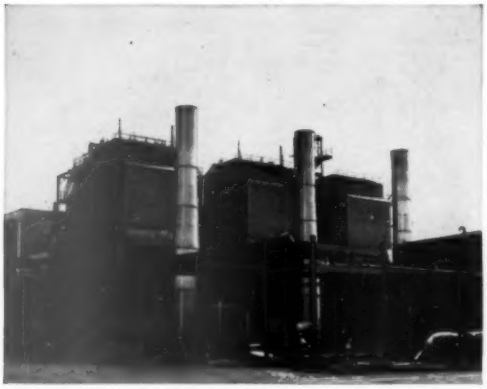

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Properties of "National" Nuclear Graphite

	AGOT Graphite	TSF Graphite
Atomic Weight	12.011	12.011
Density g/cm³	1.70	1.70
Microscopic absorption cross section (millibarns)*	4.50	3.95
Microscopic scattering cross section (barns)*	5.09	5.09
Macroscopic absorption cross section ($cm^{-1} \times 10^5$)	38.30	33.67
Macroscopic scattering cross section (cm^{-1})	0.432	0.432
Average logarithmic energy decrement per collision	0.158	0.158
SLOWING DOWN POWER	0.0684	0.0684
MODERATING RATIO	177.5	203
REFLECTING RATIO	1125	1285
DIFFUSION LENGTH	49	52

*at 2200 meters/sec.

Table shows excellent nuclear properties of "National" Nuclear Graphite. In addition, it is a structural material with superior high temperature properties.

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